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Author(s):	Narlesky, Joshua Edward Karmiol, Benjamin Kelly, Elizabeth J.
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Prompt Gamma Analysis of ARIES Materials and Updates to the 2015 Calibration Equations

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Los Alamos
NATIONAL LABORATORY

Prepared for: U.S. Department of Energy: Savannah River Operations Office

Prepared by: Joshua Narlesky,
Benjamin Karmiol,
Elizabeth Kelly

Los Alamos National Laboratory

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Executive Summary

Prompt gamma (PG) analysis is a nondestructive, nuclear, elemental analysis technique that uses charged particle reactions to interrogate a sample, and elements present in the sample matrix are identified through the characteristic gamma-rays emitted from the product nuclei in alpha-p and alpha-n nuclear reactions. This technique has been applied to plutonium oxide packaged in over 4,000 individual 3013 containers, and the concentrations of certain light elements were determined from the integrated peak areas based on a calibration that was published previously. This report provides the results for a new population of 3013 containers packaged with oxide materials produced by the conversion of metal by Advanced Recovery and Integrated Extraction System (ARIES) project using the direct metal oxidation (DMO) process and muffle furnaces. New PG and analytical chemistry data collected since 2015 were added to the existing calibration data sets to refine the calibration parameters. Calibration equations were also developed for determining beryllium and fluorine at low concentrations in high-purity ARIES product oxides. The new fluorine calibration provides an order of magnitude greater sensitivity and results in an additional 1,408 containers in the original population identified as having fluorine as an impurity. Additionally, equations for calculating the lower limits of detection (LLDs) as a function of the actual counting time (live time) were obtained using WLS regression technique for samples in the calibration data set. This resulted in changes to the LLDs published previously.

The PG analysis performed on 265 ARIES 3013 containers packaged with oxide from BL 1 through 89 identified beryllium, fluorine, chlorine, magnesium, sodium, and phosphorus as impurities in a number of containers. Beryllium was detected in 39 containers in concentrations ranging from 20 to 700 ppm. Fluorine was detected in 23 containers in concentrations ranging from 10 to 600 ppm. Chorine was detected in nine containers all from BL 84, 85, and 87. The chlorine concentration ranged from 3,000 to 11,000 ppm. Based on LLD analysis, it was determined that the use of PG for verification of the 9977 offsite transportation certificate (OTC) limits for lithium, beryllium, fluorine, and sodium in plutonium oxide would be feasible. The minimum detector live times for verification of these elements ranged from 0.9 to 4.2 hours. Although PG can detect boron, magnesium, aluminum, phosphorus, chlorine and potassium, the minimum live times required to verify the 9977 OTC limits exceed 30 hours.

Acronyms and Abbreviations

Acronym	Definition
ARIES	Advanced Recovery and Integrated Extraction System
BL	blend lot
DMO	direct metal oxidation
ISP	Integrated Surveillance Program
LANL	Los Alamos National Laboratory
LLD	lower limit of detection
MeV	mega electron-volt
MIS	Materials Identification and Surveillance Program
MOX	Mixed Oxide (fuel)
OLS	ordinary least squares
OTC	offsite transportation certificate
NDA	nondestructive analysis
PG	prompt gamma
PUREX	Plutonium Uranium Extraction
SRS	Savannah River
WLS	weighted least squares

1 Introduction

Prompt gamma (PG) analysis is a nondestructive, nuclear, elemental analysis technique that uses charged particle reactions to interrogate a sample, and elements present in the sample matrix are identified through the characteristic gamma-rays emitted from the product nuclei when alpha-p and alpha-n nuclear reactions occur [1, 2]. This technique has been applied to plutonium oxide packaged in over 4,000 DOE Standard 3013 containers to identify the light elements present in the material matrix. In 2015, a set of calibration equations were developed using the weighted least squares (WLS) regression technique and applied to the normalized peak areas obtained from the PG analysis of containers of impure plutonium oxide versus the concentration of the light elements measured by analytical chemistry [3]. Using this method, an algorithm was developed to calculate the concentration of the sensitive elements listed in Table 1-1. Savannah River Site (SRS) has been able to implement the algorithm in the Integrated Surveillance Program (ISP) Database to calculate the concentration of those elements when detected in materials packaged in 3013 containers. Lower limits of detection (LLDs) were determined for the sensitive elements using a method by Gedcke that is based on a Gaussian fit of peaks used for detection [4]. However, the LLDs were based on a small number of samples and uncertainties were not determined.

Table 1-1. Elements in plutonium oxide materials detectable by PG, lower limits of detection for 60 minute and 600 minute count times based on the 2015 analysis, and the desired limit of detection based on the 9977 offsite transportation certificate (OTC) [5].

Element	Isotope Detected	Calibration Eqn. (Y/N)	2015 Element LLD_{60} (ppm)	2015 Element LLD_{600} (ppm)	9977 OTC Limit (ppm)
Li	^{7}Li	N	200	60	440
Be	^{9}Be	Y	80	30	88
B	^{10}B	N	460	150	440
F	^{19}F	Y	2,000	640	220
Na	^{23}Na	Y	140	50	264
Mg	^{25}Mg	Y	560	180	440
Al	^{27}Al	Y	1,300	420	132
P	^{31}P	Y	8,200	2,600	100
Cl	^{35}Cl	Y	6,400	2,100	100
K	^{39}K	Y	20,000	6,400	100

The Advanced Recovery and Integrated Extraction System (ARIES) project at Los Alamos National Laboratory (LANL) has been packaging 3013 containers with oxide produced from the conversion of metal in the direct metal oxidation (DMO) process and muffle furnaces. From 2010 until the time this report was issued, 89 blend lots (BL) (265 individual 3013 containers) were packaged with ARIES oxide and received a PG measurement. Packaging of 3013 containers is expected to continue into 2023 or until the supply of empty 3013 container sets is depleted. After this time, alternative packaging for the oxide, such as SAVY 4000 containers, is under consideration. The feed materials for BL 1 through 74 comprised Pu metal from pits converted to oxide that meets Mixed Oxide (MOX) fuel specifications. However, swap material was introduced into the feed beginning with BL 75, resulting in oxide produced with impurities not observed in previous BLs. For the purposes of this report, the material in BL 1 through 74 is referred to as high-purity ARIES product oxide.

In addition to PG, BL 1 through 77 had analytical chemistry available at the time of writing this report. However, the ARIES project is considering the discontinuation of the analytical chemistry measurements for BLs in the future. If analytical chemistry is discontinued, characterization of the oxide would rely on other methods, such as including PG analysis, to ensure that the packaged materials meet the impurity limits for the 9977 shipping packages as defined in the OTC. PG analysis would be a desirable method for determining the impurity content for these materials because it is nondestructive, and the necessary data could be collected at the same time as the required calorimetry and gamma-ray isotopic measurements.

This report presents and discusses the updated calibration equations, and the PG results for ARIES 3013 containers from BL 1 through 89. The calibration equations used to calculate the impurity concentration were updated with data collected since 2015. The new data include measurements performed on ARIES materials using standard 60-minute counts and extended counts performed on the ARIES NDA Table. Data from the destructive evaluation of 3013 containers and their contents in the 3013 surveillance program from 2015 through 2018 was also included. ARIES materials have a higher actinide content and lower impurity content than other materials in the data set; therefore, the ARIES data set was examined for systematic differences in the sensitivity of the PG signal with respect to the sensitivities derived from impure oxides. Systematic differences were observed in the beryllium signal for high-purity ARIES product oxide, so a separate calibration was necessary for those materials. New calibration equations were obtained using the WLS technique with the updated data sets, and a separate calibration was developed for determination of beryllium in high-purity ARIES materials. Also, a new calibration was developed for fluorine using a more intense peak in the spectrum. It was found that this more intense fluorine peak could be used in less pure materials if the appropriate interference corrections were made. Equations for calculating the LLDs as a function of the actual count time (detector live time) were also obtained for each of the sensitive elements (with the exception of lithium and boron, which have few data) using WLS regression technique for the calculated LLD and the spectrum live time for samples in the updated calibration data set. The LLDs were then used to determine the minimum counting times required to detect each of the detectable elements at the 9977 OTC limits.

2 Data and Methods

The data used in the regression analyses were obtained from standards, which have both analytical chemistry and PG analysis data. PG analysis is performed on the bulk material (generally 100 g up to 5 kg of material), and the analytical chemistry is performed on a sample (1-10 g) extracted from the bulk material. The standards included in these analyses belong to one of the groups listed below.

1. Samples in the Materials Identification and Surveillance (MIS) program. These samples were obtained from the various DOE sites before thermal stabilization for packaging according to the 3013 standard. This group of samples as a whole is considered representative of all the materials packaged in 3013 containers.
2. Samples of thermally stabilized material destructively analyzed at the DOE packaging sites.
3. Samples obtained during the destructive analysis of 3013 containers from FY07 through FY18 after storage for a prescribed period of time.
4. Oxide materials produced in the magnesium hydroxide precipitation process from the plutonium uranium extraction (PUREX) from product quality nitrate solution. Analytical chemistry for the feed items indicates that the total impurities are generally less than one percent. Analytical chemistry is not available on the oxide materials, but the magnesium concentration can be calculated based on the assumption that the major components are plutonium oxide and magnesium oxide. The plutonium oxide concentration is available from NDA.
5. Oxide materials produced by the ARIES program. This data set comprises material from BL 1 through 77. These materials are all greater than 85.7% Pu and have both PG analyses and analytical chemistry completed as of March 2021.

The evaluation and selection of the analytical chemistry and PG data from each of the standards in groups 1 through 4 for inclusion in the regression model was described previously and was based on several factors including the distribution of the light elements in the material matrix, the measurement conditions for analytical chemistry and PG analysis, and the analytical chemistry technique used [3]. The ARIES data set included analytical chemistry from 77 BLs packaged into 229 individual 3013 containers. PG measurements were performed on each 3013, but the analytical chemistry was performed on the BL. Analytical chemistry data were available for all of the detectable elements in Table 1-1, but only beryllium, fluorine, and phosphorus were present in concentrations that could be detected within the count times used. Multiple analytical chemistry measurements for a given BL were averaged, and the PG was taken as the average normalized peak area for all containers within a given BL.

2.1 PG Data

The PG data is obtained by performing counts of individual 3013 containers using high-resolution, coaxial high-purity germanium detectors. Although the measurements of all of the ARIES materials were performed on 3013 containers, this method is not restricted to the 3013 container geometry. Measurements were typically performed in the NDA lab, but extended counts were obtained on the ARIES NDA table. The gamma-ray spectrum files are analyzed with Prompt Gamma Analysis Software v4.7 developed at Los Alamos National Laboratory [3, 6]. The analysis software computes the normalized peak areas for the peaks that correspond with alpha-particle-induced reactions. The normalized peak areas PG_i are unitless quantities and are obtained by determining the net counts P_i for a given peak and dividing by the normalization factor n and the attenuation factor A_i as shown in Eq.(1). The net counts were obtained by determining the gross counts G_i and subtracting the average background B_i. The gross counts are the sum of the counts c in the ROI containing the j channels corresponding to the peak.

$$PG_i = \frac{P_i}{n \cdot A_i} = \frac{G_i - B_i}{n \cdot A_i} = \frac{\sum_{j\text{ channels}} c_j - B_i}{n \cdot A_i} \tag{1}$$

The normalization factor is obtained from the net counts from the ^{239}Pu gamma-ray peak at 0.414 MeV ($n_{414\ kev}$) and the ^{241}Am gamma-ray peak at 0.662 MeV ($n_{662\ kev}$), as shown in Eq. (2)

$$n = \left(\frac{n_{414\,\text{kev}}}{A_{414\,\text{kev}}} \cdot \frac{S_{Pu-239}}{s_{\text{Pu-239}}} + \frac{n_{662\,\text{kev}}}{A_{662\,\text{kev}}} \cdot \frac{S_{Am-241}}{s_{\text{Am-241}}} \right) 10^{-6}\ \text{[counts]}, \tag{2}$$

where $S_{Pu\text{-}239}$ and $S_{Am\text{-}241}$ are the specific alpha activities of ^{239}Pu and ^{241}Am and $s_{Pu\text{-}239}$ and $s_{Am\text{-}241}$ are the specific gamma activities of ^{239}Pu at 0.414 MeV and ^{241}Am at 0.662 MeV, respectively. The attenuation factor A_i is applied to correct for the differences in thickness for the various container configurations that may be counted. For example, the material may be counted in its packaged state in the 3013 container, which is a nested configuration consisting of the outer 3013 container, the inner container, and the convenience container, or it may be counted in just the convenience container. For a given container configuration, the attenuation factor is calculated from Eq. (3)

$$A_i = \exp\left[-\left(\mu / \rho \right)_i \cdot \rho \cdot t \right], \tag{3}$$

where the quantity (μ/ρ) is the mass attenuation coefficient for the steel for the energy of gamma-ray peak i, ρ is the density of the steel, and t is the total wall thickness of the steel containers.

Various absorbers may be used to shield the counting system from the low-energy gamma-rays from ^{241}Am to reduce the dead time. Historically, the use of absorbers has not been recorded; however, and equivalent thickness of lead may be determined empirically using the ratio χ of the ^{239}Pu gamma-ray peak at 0.414 MeV to the ^{239}Pu gamma-ray peak at 0.646 MeV. It has been demonstrated that values of χ less than or equal to 39 indicate that the attenuation is significant, and a correction must be applied. This is done by determining the absorber thickness t from the χ using Eq. (4).

$$\begin{aligned} &t = 1.26 - 0.31 \cdot \ln(\chi)\ \ (\chi < 39)\ \text{[in]} \\ &t = 0\ \ (\chi \geq 39) \end{aligned} \tag{4}$$

The attenuation caused by the absorbers (if present) can then be calculated using Eq. (3) substituting the appropriate density and the mass attenuation coefficients for each gamma-ray peak.

2.2 LLD Data

The LLDs for the sensitive light elements in plutonium oxide were obtained using a method described by Gedcke in which a Gaussian distribution is used to model the difference between the observed counts and background counts (the difference of two Poisson distributions) [7]. This method relies on the assumptions that the Gaussian distribution is a good approximation to the Poisson distribution and that concentration C is equal to some constant k multiplied by the integrated net peak area P. The net area of the peak is obtained by subtracting the background B from the total integrated area. The background is estimated by integrating two additional regions of width ($\eta_B/2$) at equal distances to the left and right of the peak. The value of η_B is arbitrary, but was selected so that neighboring peaks were avoided. The parameter η_P is the peak width, and L is the live time. The LLD is the value for which there is only a 5% chance of a false positive and a 5% chance of a false negative and is calculated using Eq. (5).

$$C_L = 2 \cdot z \cdot C \sqrt{\left(1+\frac{\eta_P}{\eta_B}\right)} \Big/ \sqrt{\left(\frac{P}{B}\right) \cdot \left(\frac{P}{L}\right) \cdot L} \quad [\text{ppm}], \tag{5}$$

Values of C_L were obtained using these parameters for each of the standards in the data by substituting the concentration calculated from the normalized peak area (C_0) and a z-score (z) of 1.6449 for a 90% confidence interval.

As shown in Eq. (5) the LLD depends on the peak to background ratio P/B, net counting rate P/L, and the live time (L). The parameter that can be altered to improve detection is the live time. When longer count times are used, the LLD changes proportionally with $1/\sqrt{L}$.

2.3 Weighted Least Squares Models

Previous work has shown that the variability of PG data increases with concentration [4]. A method such as OLS that treats all of the data equally would give less precisely measured points more influence than they should have and would give highly precise points too little influence. In addition, larger values tend to have greater influence than smaller values. Therefore, it is not reasonable to assume that every observation should be treated equally. Weighted least squares can be used to optimize parameter estimation by giving each data point its proper amount of influence over the parameter estimates, and there is scientific justification for decreased precision at higher concentration. The WLS method can apply weight factors to the observations so that the observations with larger values of concentration have less influence. This gives two big advantages: more precise parameter estimates and better and more defensible estimates of uncertainties [8, 9].

The prompt gamma normalized peak area PG_C and the analytical chemistry data C_C are being fit to a model of the form shown in Eq.(6),

$$PG_{C,k} = \beta_C C_{C,k} + \varepsilon, \tag{6}$$

where ε is the random error term.

The same method has been applied to the LLDs to determine C_L as a function of live time. In this case, live time parameter PG_L and C_L are being fit to a model in the form shown in Eq. (7)

$$PG_{L,k} = \beta_L C_{L,k} + \varepsilon \tag{7}$$

where

$$PG_{L,k} = 1\big/\sqrt{L}\ . \tag{8}$$

Because the models used for the regression analyses of the impurity concentration (C_C) and the LLD (C_L) are the same, the subscripts C and L are omitted for the remainder of this section.

Both models will result in straight line through the origin with a slope β. The parameter β is essentially the sensitivity. The parameter β_C has units of signal per ppm concentration, and the parameter β_L has units of time$^{-0.5}$ per ppm concentration. It is assumed that the PG signal is zero at a concentration or a live time of zero.

In OLS, the residual sum of squares RSS is minimized to find the parameter β in Eq. (9)

$$RSS = \sum_{k=1}^{m} \left(PG_k - C_k * \beta \right)^2 , \tag{9}$$

where m is the sample size. In this case the variance of ε is assumed to be constant for all C_k. In weighted least squares regression, RSS is weighted by weight factor w_i to give the weighted residual sum of squares WSS in Eq. (10).

$$WSS = \sum_{k=1}^{m} w_k \left(PG_k - C_k * \beta \right)^2 \tag{10}$$

This expression is equivalent to RSS in OLS when all w_k are equal to 1. In the WLS model, we chose weight factors equal to $1/C_k$ because the data indicate variances proportional to C_k. When the weight factors are applied, the assumption of constant variance holds true.

The standard error for the weighted regression se_w was determined from Eq. (11)

$$se_w = \left[\sum_{k=1}^{m} \left(PG_k - \overline{PG_w} \right)^2 - \frac{\left(\sum_{k=1}^{m} \left(C_k - \overline{C_w} \right)\left(PG_k - \overline{PG_w} \right) \right)^2}{\sum_{k=1}^{m} \left(C_k - \overline{C_w} \right)^2} \right] \Big/ df \tag{11}$$

where the degrees of freedom $df = m - 1$ because the intercept term is not used. The terms $\overline{PG_w}$ and $\overline{C_w}$ are the weighted averages of the PG data and analytical chemistry data, respectively.

For a new observation PG_0, the impurity concentration (C_C) or the LLD (C_L) is then obtained using the inverse calibration shown in Eq.(12).

$$C_0 = \frac{1}{\beta} \cdot PG_0 \tag{12}$$

The standard error associated with C_0 is given by Eq. (13)

$$se_{C_0} = \frac{se}{\beta}\sqrt{\frac{1}{w_0} + \frac{1}{\sum w_i} + \frac{\left(PG_0 - \overline{PG_w}\right)^2 \sum w_i}{\beta^2\left(\sum w_i \sum w_i C_i^2 - \left(\sum w_i C_i\right)^2\right)}} \tag{13}$$

where $w_0 = 1/C_0$.

The two-sided confidence intervals for C_0 are then given by Eq. (14)

$$CI_0^{\pm} = C_0 \pm t(m-1,\ \alpha/2)\cdot se_{C_0} \tag{14}$$

where $t(m-1,\ \alpha/2)$ is the *t*-distribution with degrees of freedom $df = m-1$ and probability $\alpha/2$ (the desired confidence level). Although denoted as confidence intervals, these may be used as inverse prediction limits. These limits correspond to selecting two limits $C_0^{\pm}$, which are derived from the prediction uncertainties on PG_0. The term C_0^- is the analytical chemistry value where the lower prediction limit for PG_0 intersects the upper prediction uncertainty equation, and C_0^+ is the value where the upper prediction limit intersects the lower prediction uncertainty equation.

3 Results and Discussion

3.1 Updated Calibration Parameters from WLS Regression

The WLS method was used to fit the updated dataset of PG data PG_C and the analytical chemistry data C_C to a linear model of the form shown in Eq. (6) for beryllium, fluorine, sodium, magnesium, aluminum, phosphorus, chlorine, and potassium as was done previously. The fits were then used to obtain inverse calibration equations to estimate the concentration of these elements from PG using the inverse sensitivity $1/\beta$. Additional calibration equations were obtained for fluorine using the higher intensity 1.274 MeV peak, for magnesium using the 2.028 MeV peak, which is free of sodium interference, and for beryllium in high-purity ARIES product oxide. The updated calibration parameters for calculating the concentration of each element and the parameters for calculating the uncertainties are given in Appendix A. Substituting the normalized peak area PG_C and the appropriate value of β_C into Eq. (12) gives the concentration. The uncertainty is calculated using Eq. (13).

3.1.1 *High Sensitivity Fluorine Calibration*

The previous set of calibration equations developed in 2015 used the 0.891 MeV peak to determine the concentration of fluorine, and the LLD_{60} and LLD_{600} were reported to be 2,000 and 640 ppm, respectively. The peak at 1.274 MeV was not used previously due to its interference with magnesium. However, it is necessary to increase the sensitivity of PG in order to detect fluorine below the 9977 OTC limit of 220 ppm. Based on the reported relative intensity, using the 1.274 MeV peak would increase the sensitivity by a factor of 3.6, which would be sufficient for detection of fluorine with a 10-hour count. Additionally, the PG for the high-purity ARIES product oxide from BL 1 through 83 and prior did not have detectable magnesium, so use of the 1.274 MeV peak would be ideal. Reanalysis of the PG spectra for the ARIES materials found fluorine in four BLs prior to BL 84, but the data were insufficient for a calibration. Therefore, the impure oxide data set was used to develop the calibration for fluorine.

The raw data for the 1.274 MeV peak can include contributions from both fluorine (component *i*) and magnesium (component *j*) when they are both present. Calculation of the fluorine contribution to the 1.274 MeV peak PG_i is done according to Eq. (15)

$$PG_i = PG_{i+j} - I_j PG_j \tag{15}$$

where PG_{i+j} is the total peak area of the 1.274 MeV peak from both the fluorine and magnesium components, PG_j is the peak area of the magnesium peak at 1.779 MeV, and I_j is the intensity of the magnesium signal at 1.274 MeV relative to the magnesium signal at 1.779 MeV. An additional correction was also made to remove the small sodium contribution to the 1.779 MeV peak. This resulted in the expression for the fluorine contribution to the 1.274 MeV peak as shown in Eq. (16).

$$PG_{F,1.274\text{ MeV}} = PG_{1.274\text{ MeV}} - 0.86\left(PG_{1.779\text{ MeV}} - 0.028 \cdot PG_{1.808\text{ MeV}}\right) \tag{16}$$

The value for the relative intensity for the sodium contribution to the 1.779 MeV peak was obtained from the literature [10], and the value for the magnesium contribution to the 1.274 MeV peak was obtained from the analysis of high magnesium materials without fluorine in 3013 containers.

Results and Discussion

The WLS result for the fluorine PG and analytical chemistry data is shown in Figure 1. The fluorine concentration range for the data set is 38 to 229,000 ppm. The data set includes one outlier with 111,000 ppm fluorine that shows a lower than expected PG signal. The reason for this difference is not known, but it is possible that the fluorine is in a chemical form that has less contact with the alpha-emitting plutonium.

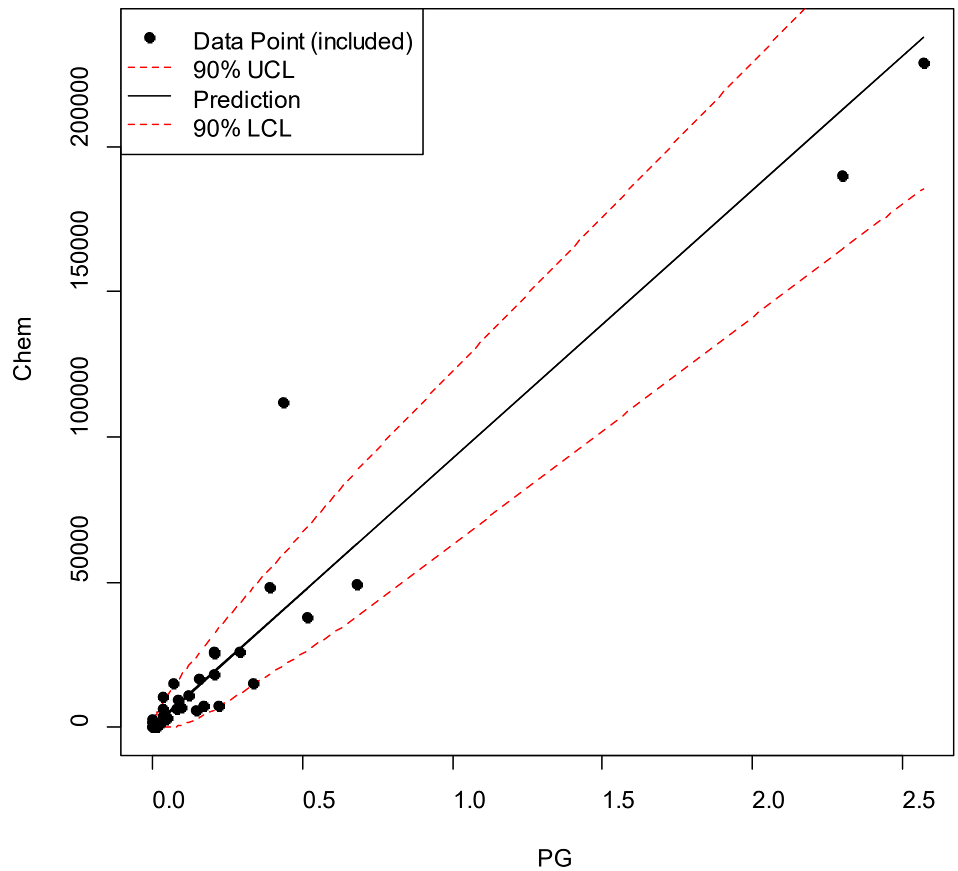

Figure 1. Fluorine calibration for 1.274 MeV peak with 90% confidence intervals.

3.1.2 *High Sensitivity Beryllium Calibration for High-Purity ARIES Materials*

The ARIES PG and analytical chemistry data were used to develop a calibration for beryllium in high-purity ARIES product oxide. The analytical chemistry data was taken as the average of the beryllium by atomic emission spectroscopy and the beryllium by mass spectroscopy if provided for the BL. The PG data were taken as the average of the normalized peak areas from all of the PG spectra that pertain to that BL. The BL included in the calibration are listed in Figure 4, and the WLS result for the beryllium in ARIES PG and analytical chemistry data is shown in Figure 2. The statistical analysis found one outlier from BL 75 that was excluded from the model. The BL 75 data point had a lower than expected beryllium signal, but the difference is believed to be due to the introduction of swap material into the feed, which introduced additional impurities. This is consistent with the analytical chemistry, which indicates several hundred ppm of other light elements including phosphorus (detected by PG), fluorine (detected by PG), and chlorine (not detected by PG) that may have contributed to the reduction in signal. Therefore, the high-sensitivity beryllium calibration should only be used for high purity materials (>85% actinide) similar to those in BL 1 thorough 74 with no other impurities detected by PG.

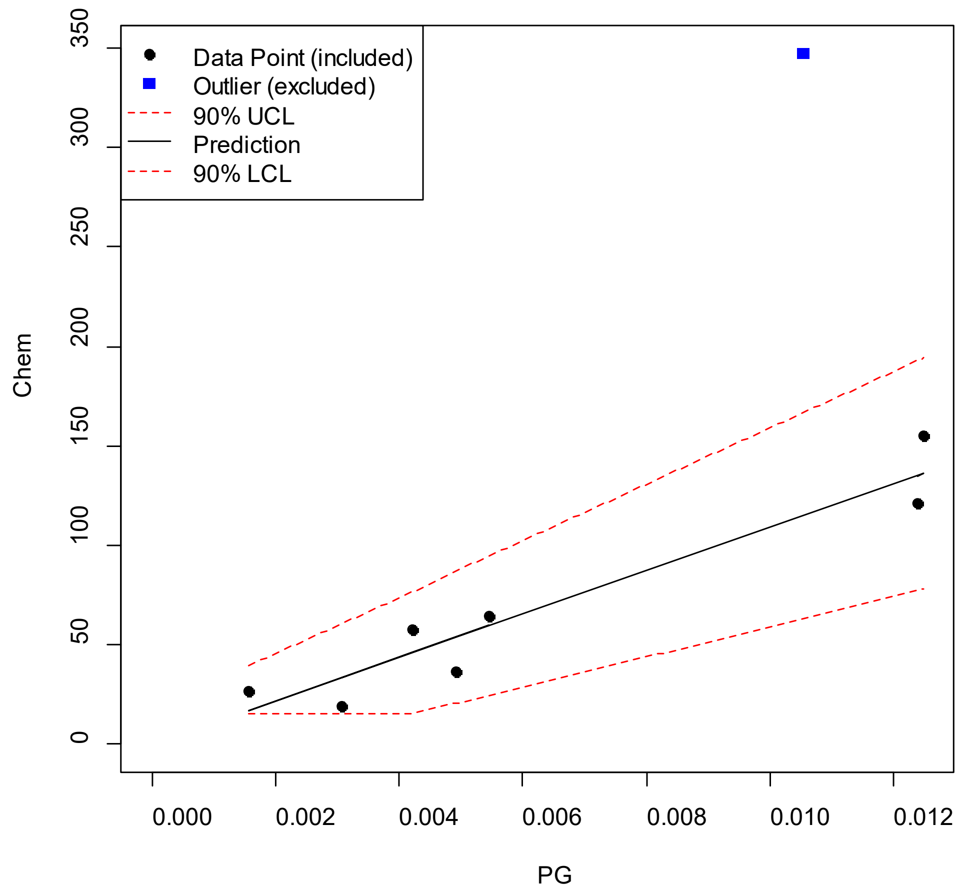

Figure 2. Beryllium calibration for high-purity ARIES product oxide with 90% confidence intervals.

3.2 Updated LLDs from WLS Regression Analysis

The LLDs for the elements were previously determined using the method by Gedke described earlier [4, 7]. The data set used to obtain the LLDs was a subset of standards (five each per element except for lithium and boron that each had two) with varying live time. To refine the LLDs and determine the uncertainty in the LLD, the WLS method was used to determine the LLD as a function of live time using the calibration data set. Linear models were constructed for beryllium, fluorine, sodium, magnesium, aluminum, phosphorus, chlorine, and potassium between the count time parameter PG_L and the concentration C_L of each standard in the form shown in Eq. (6). The fits were then used to obtain inverse calibration equations to estimate the LLD concentration of these elements from the count time parameter using the inverse sensitivity $1/\beta$. Calibration equations were obtained for the fluorine LLD using the higher intensity 1.274 MeV peak, for magnesium LLD using the 2.028 MeV peak, and for the LLD of beryllium in high-purity ARIES product oxide. The calculated LLDs for 60 and 600 minute live times are given in Table 3-1. Lithium and boron did not have sufficient data to construct a model, so the LLDs are unchanged from the previous report. The calibration parameters used to determine the LLD for any live time according to Eq. (12) and the parameters for calculating the uncertainty according to Eq. (13) are given in Appendix A.

Table 3-1. Sensitive elements for PG analysis and lower limits of detection for the revised calibration equations.

Element	Peak [MeV]	Applicability	Conc. Eqn. (Y/N)	Element LLD_{60} [ppm]	Element LLD_{600} [ppm]	9977 OTC Limit [ppm] [5]
Lithium	0.478	All	N	*200	*60	440
Beryllium	4.439	Impure oxide	Y	130	40	88
		High-purity ARIES product	Y	20	6	
Boron	3.684	All	N	*460	*150	440
Fluorine	0.891	All	Y	1,000	320	220
	1.274	High-purity ARIES product All: interference correction reqd.	Y	70	20	
Sodium	1.808	All	Y	180	60	264
Magnesium	1.779	All	Y	1,900	600	440
	2.028	All	Y	2,400	750	
Aluminum	2.236	All	Y	900	300	132
Phosphorus	2.127	All	Y	1,800	600	100
Chlorine	2.167	All	Y	6,700	2,100	100
Potassium	1.524	All	Y	22,000	7,000	100

*Limited data. LLD analysis based on 2 points and unchanged from original analysis.

Comparing Table 1-1 and Table 3-1, it is apparent that a number of the LLDs have changed since they were originally published [3, 4]. The largest changes in the LLDs occurred for fluorine, magnesium, and phosphorus. The LLDs for fluorine from the 0.891 MeV peak have decreased by a factor of 2 from those previously published. It appears that the points selected for the original analysis had higher LLD values by chance and that using the full data set reduced the LLDs. For magnesium, a correction for the sodium interference has since been implemented. Removing the interference reduces the PG signal, and the resulting LLD was higher. In the case of phosphorus, inclusion of additional data collected since 2015 especially at low concentrations resulted in lower LLDs.

Table 3-1 also includes LLDs for the new calibrations that have been added as a result of this work. The calibration for beryllium in high-purity ARIES product oxide gives a factor of 6 increase in the sensitivity, and the calibration for fluorine increases the sensitivity by an order of magnitude. The LLD_{60} values for both of these elements are well below the 9977 OTC limits. This work also included a calibration for magnesium using the 2.028 MeV peak. The LLDs indicate that this peak is less sensitive but more reliable because it is not affected by interferences. However, it is unlikely that determining magnesium concentration based on the 2.028 MeV normalized peak will be useful for all except very impure materials.

3.3 Impurities Detected in ARIES Materials

PG analysis was performed on 265 ARIES 3013 containers packaged with oxide from BL 1 through 89. Each container was counted at least one time. The actual count times (or live times) for the original measurements vary from 10 to 130 minutes as shown in Figure 3. For many of the items, the counting time was set for one hour; however, the actual counting time (live time) was less than one hour due to detector dead time. Additional long counts of 10 to 20 hours (not shown) were performed on five of the containers using the NDA table.

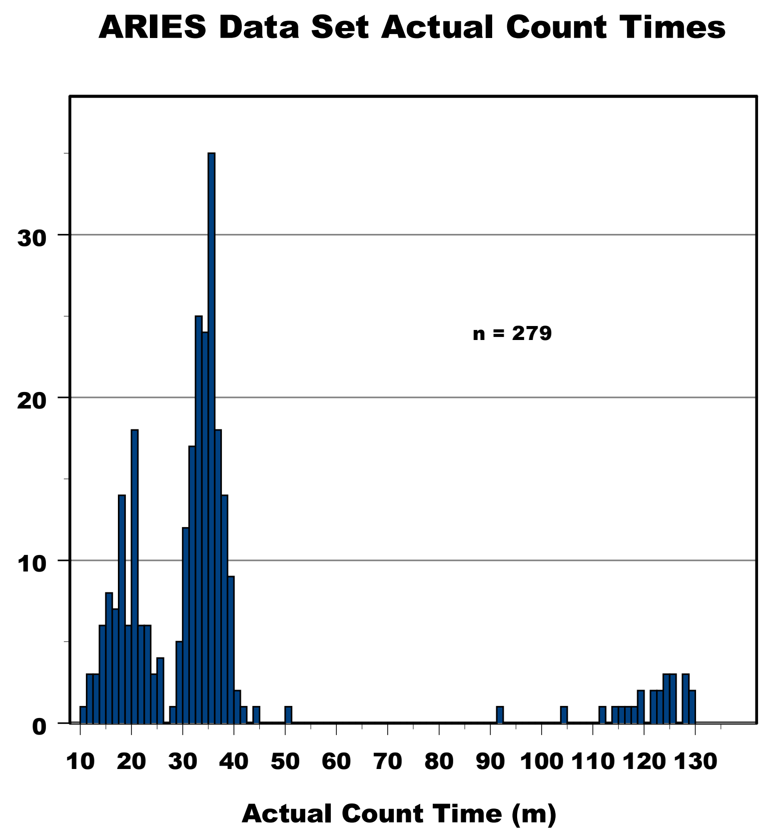

Figure 3. Histogram showing the actual count times (live times) for ARIES 3013 containers.

The elements detected in the ARIES materials in BL 1 through 89 by PG analysis included beryllium, fluorine, magnesium, sodium, phosphorus, and chlorine. Lithium, boron, aluminum, and potassium were not detected in these materials. The BLs and 3013 containers with these impurities are listed in Table 3-2. The impurity concentrations were calculated with the new calibration equations and are given in Appendix B.

Table 3-2. Blend lots with impurities detected by PG analysis.

BL No.	3013 ID	Live Time (hr)	Al	Be	Cl	F	Mg	P	Na
0004	A000317	0.6							Na
	A000546	0.6							
	A000584	0.6							
0006	A000486	0.6		Be					Na
	A000574	0.5		Be					
	A000688	0.5		Be					
0008	A000638	0.5							Na
	A000466	0.5							
	A000619	0.6							
0022	H003016	0.6		Be					
	H003171	0.5		Be					
	H003239	0.5		Be					
0025	H003190	0.5		Be					
	H003234	0.6		Be					
	H003238	0.6		Be					
0031	H002978	0.6							Na
	H002948	0.6							
	H002929	0.6							
0033	H002904	13.5*		Be		F			
	H002907	0.5							
	H002923	0.6							
0034	H002911	0.6		Be					
	H002924	0.6		Be					
	H002944	0.6		Be					
0050	H002878	0.6		Be					
	H002892	0.6		Be					
	H002897	0.6		Be					
0061	A002015	0.3				F			
	A002054	0.3				F			
	A002082	0.3				F			Na
0067	A002122	0.3		Be					
		8.1*		Be					Na
	A002123	0.4		Be					
	A002124	0.4		Be					
0075	A002547	0.3		Be		F		P	
	A002548	0.3		Be		F		P	
	A002549	0.2		Be		F		P	
0076	A002083	0.4		Be					
	A002102	0.4		Be					
	A002108	0.3		Be					
0077	A002138	6.8*		Be					
	A002142	0.4							
	A002339	0.3							
0079	A002166	6.8*		Be		F			

BL No.	3013 ID	Live Time (hr)	Al	Be	Cl	F	Mg	P	Na
	A002187	0.4							
	A002180	0.3							
0083	A002125	0.6		Be					
	A002186	0.4		Be					
	A002333	0.4		Be					
0084	A002514	0.4		Be	Cl	F	Mg		Na
	A002515	0.2		Be	Cl	F	Mg		Na
	A002519	0.4		Be	Cl	F	Mg		Na
0085	A002562	0.5		Be	Cl	F	Mg		Na
	A002576	0.5		Be	Cl	F	Mg		Na
	A002584	0.5		Be	Cl	F	Mg		Na
0086	A002582	0.5				F	Mg		
	A002583	0.5				F			
	A002586	0.5				F	Mg		
0087	A002557	0.6		Be	Cl	F	Mg		Na
	A002575	0.6		Be	Cl	F	Mg		Na
	A002585	0.5	Al	Be	Cl	F	Mg		Na
0088	A002550	0.4				F	Mg		
	A002573	0.4				F	Mg		
	A002589	0.4				F	Mg		
0089	A002559	0.5					Mg		Na
	A002565	0.5					Mg		Na
	A002570	0.5					Mg		Na
Total containers with impurities detected--			**1**	**39**	**9**	**23**	**17**	**3**	**18**
* Indicates extended counts performed on the ARIES NDA Table									

3.3.1 *Results for Beryllium*

Beryllium was the impurity detected most frequently in the ARIES materials, and the beryllium concentrations in high-purity ARIES materials were found to be systematically higher than the concentrations from analytical chemistry by a factor of 6 on the average when the original calibration parameters were used for high-purity ARIES product oxides. A comparison of the PG results from the original parameters and the analytical shown in Figure 4 indicate that the high-purity ARIES product oxides yield a stronger signal for beryllium in high-purity materials. When other impurities are present, such as in BL 33 and 75, the systematic difference is smaller, and the standard calibration parameters for impure oxides can be used.

Results and Discussion

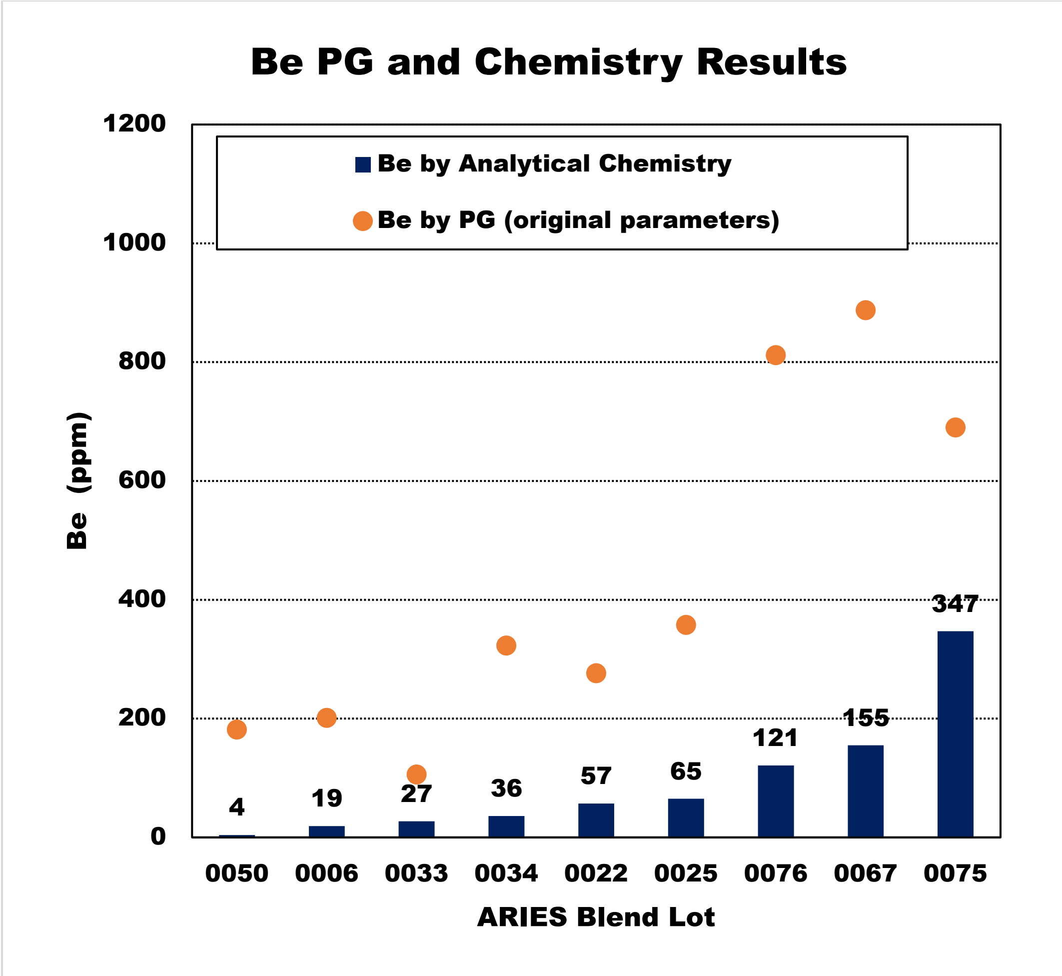

Figure 4. Comparison of the analytical chemistry data and the PG results from the original calibration parameters.

A comparison of the analytical chemistry data and the PG results from the high-sensitivity beryllium calibration is shown in Figure 5. PG did not detect other impurities in these materials, so the high-sensitivity calibration parameters were used. The average beryllium concentration from all containers in the BL is shown by the points, and the error bars are used to indicate the range of concentrations measured for the containers in each BL. The red line indicates the LLD for a 30 minute live time. The concentrations from the high-sensitivity calibration show better agreement with the analytical chemistry results for these containers than the concentrations obtained with the standard calibration for impure oxide or the original calibration parameters. As mentioned previously, analytical chemistry was performed on a sample of material taken from the BL, but each 3013 giving multiple PG measurements for a given BL. The range of beryllium concentrations for each BL seems to vary independent of concentration, which suggests that the BLs are homogenous.

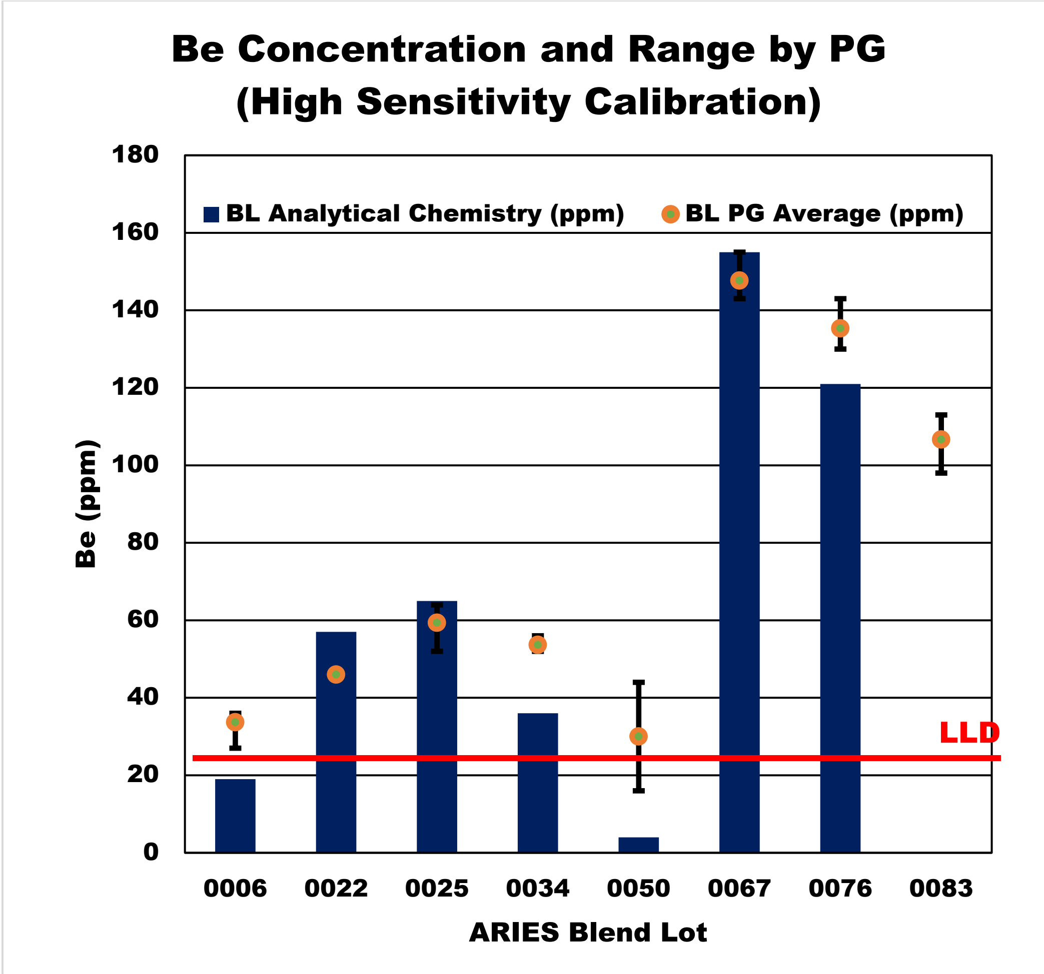

Figure 5. Comparison of beryllium measurements by PG and analytical chemistry for BLs that use the high-sensitivity calibration. Error bars indicate the range of the PG measurements for the individual containers. Analytical chemistry was not available for BL 78 through 89.

A comparison of the analytical chemistry data and the PG results from the standard beryllium calibration for impure oxide is shown in Figure 6. PG detected other impurities in these materials, so the high-sensitivity calibration parameters could not be used. The average beryllium concentration from all containers in the BL is shown by the points, and the error bars are used to indicate the range of concentrations measured for the containers in each BL. The red line indicates the LLD for a 30 minute live time. The ranges of the beryllium concentrations for each BL are similar in magnitude to those found in the high-purity materials, which suggests that these BLs are also homogenous.

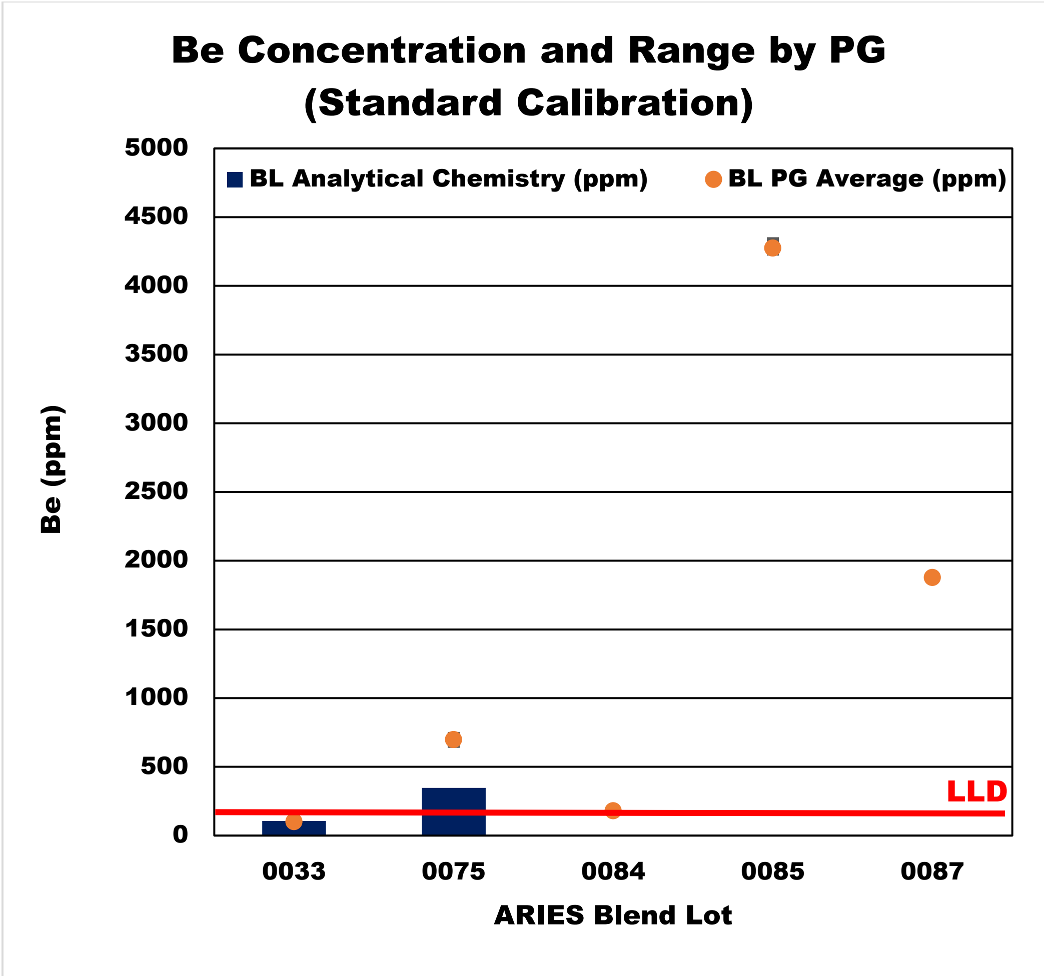

Figure 6. Comparison of fluorine measurements by PG and analytical chemistry for BLs that use the standard calibration. Error bars indicate the range of the PG measurements for the individual containers. Analytical chemistry was not available for BL 78 through 89.

3.3.2 *Results for Fluorine*

Fluorine was not detected in the original analyses performed for BL 1 through 84, which used the sixth-most intense peak at 0.891 MeV. This result is consistent with the 60 minute LLD, which is higher than the fluorine concentrations in those materials as determined by analytical chemistry. However, when the full set of ARIES spectra were examined for the presence of the 1.274 MeV peak, fluorine was detected in 23 of the ARIES 3013 containers. The fluorine concentrations calculated from the PG results were consistent with those measured by analytical chemistry indicating that the sensitivity for fluorine in ARIES materials is the same as the sensitivity for fluorine in lower purity material.

A comparison of the analytical chemistry data and the PG results from the fluorine calibration using the 1.274 MeV peak is shown in Figure 7. The average fluorine concentration from all containers in the BL is shown by the points, and the error bars are used to indicate the range of concentrations measured for the containers in each BL. The red line indicates the LLD for a 30 minute live time. Unlike the beryllium measurements, the 1.274 MeV peak has interferences from magnesium. Therefore, the BLs with magnesium have a higher container-to-container variability, and are not useful for judging homogeneity of BLs.

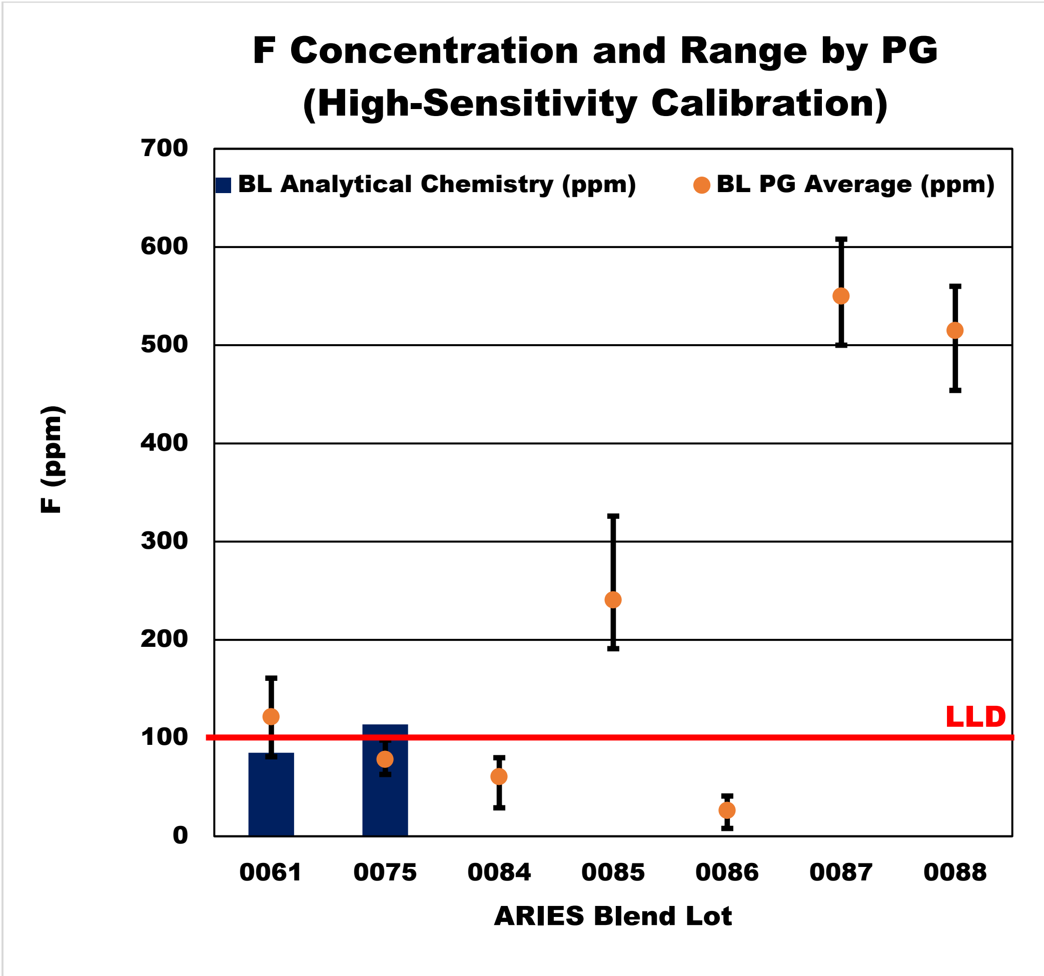

Figure 7. Comparison of fluorine measurements by PG and analytical chemistry for BLs that use the high-sensitivity calibration. Error bars indicate the range of the PG measurements for the individual containers. Analytical chemistry was not available for BL 78 through 89.

3.3.3 *Results for Salts (chlorine, magnesium, and sodium)*

Impurities associated with chloride salts (chlorine, sodium, and magnesium) were detected in several BLs from 84 to 89. The presence of these elements indicates that chloride salts were present in the feed material, which included swap material. Most of the magnesium chloride, if present in the feed material, would be converted to magnesium oxide when calcined to 950 °C as required by DOE-STD-3013. Therefore, the major chemical forms of these elements are expected to be NaCl and MgO.

Chlorine was detected in BL 84, 85, and 87 along with sodium and magnesium. The average chlorine concentration for each of those BLs is shown in Figure 8 along with the error bars that represent the range of concentrations measured for the containers in each BL. The red line indicates the LLD for a 30 minute live time. The chlorine measurements have a higher container-to-container variability than other elements despite not having interferences. The source of the variability may be due to the weak signal as indicated by the high LLD.

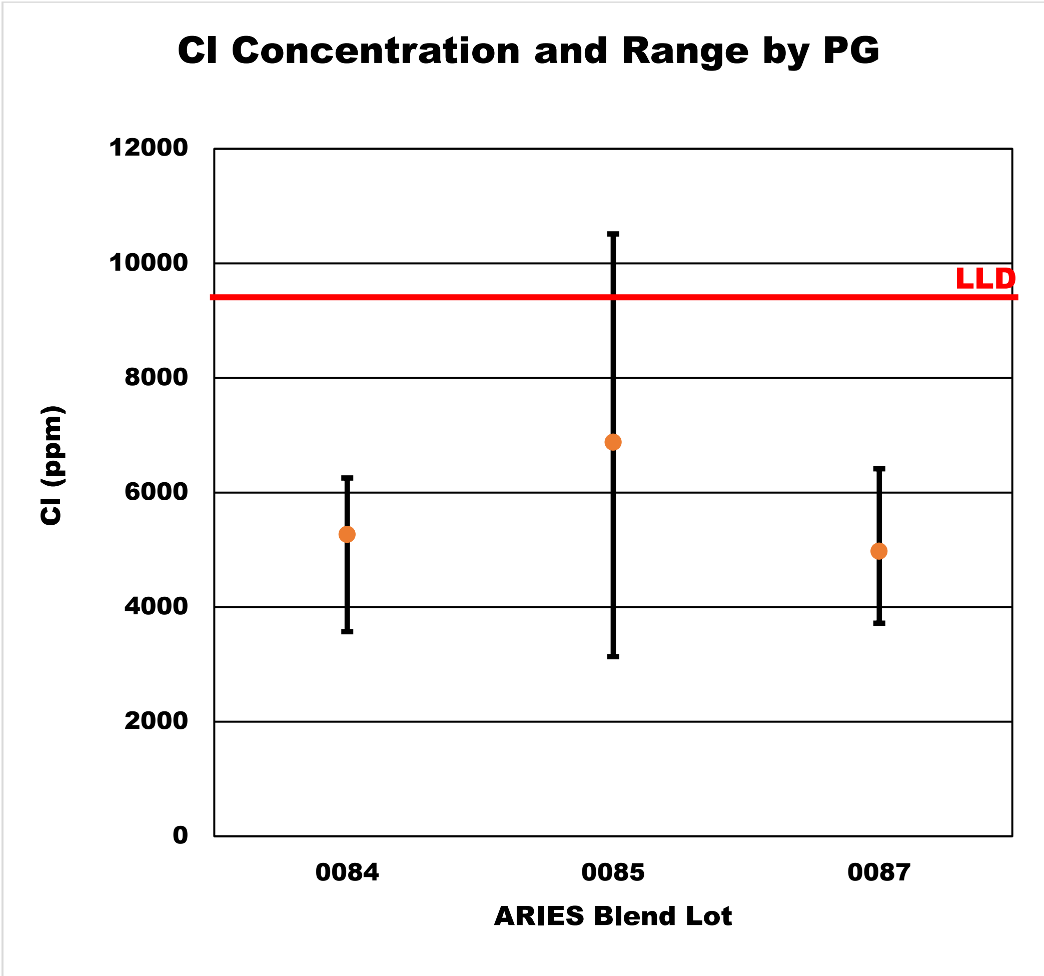

Figure 8. Comparison of chlorine measurements by PG and analytical chemistry. Error bars indicate the range of the PG measurements for the individual containers. Analytical chemistry was not available for BL 78 through 89.

Magnesium was detected in BL 84 through 89. The average magnesium concentration for each of those BLs is shown in Figure 9 along with the error bars that represent the range of concentrations measured for the containers in each BL. The red line indicates the LLD for a 30 minute live time. The magnesium measurements have a higher container-to-container variability than other elements, which may be due to interference with sodium and a weak signal as indicated by the high LLD.

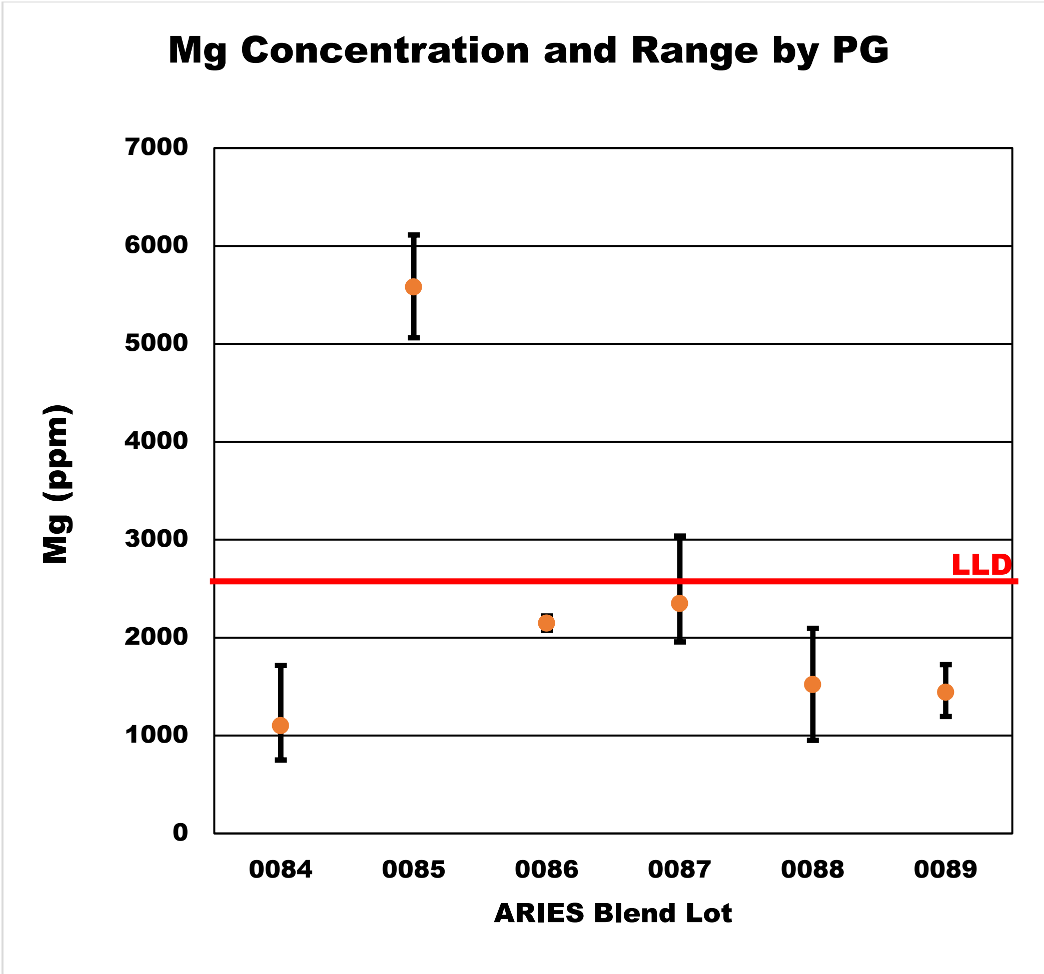

Figure 9. Comparison of magnesium measurements by PG and analytical chemistry. Error bars indicate the range of the PG measurements for the individual containers. Analytical chemistry was not available for BL 78 through 89.

Sodium was detected in BL 84, 85, 87 and 89. The average sodium concentration for each of those BLs is shown in Figure 10 along with the error bars that represent the range of concentrations measured for the containers in each BL. The red line indicates the LLD for a 30 minute live time. The sodium measurements have a relatively low container-to-container variability than other elements, which suggests that the BLs are homogeneous.

Sodium was also detected sporadically in high-purity ARIES product oxide. Examination of the analytical chemistry data shows that the sodium concentrations as determined by PG were higher than the analytical chemistry results typically by an order of magnitude. Additionally, sodium was not detected consistently for all of the containers within a particular BL, and no other chloride salt components were detected in these materials. Therefore, the observations of sodium in in high-purity ARIES product oxide may be due to an unknown interference at 1.810 MeV with the primary peak for sodium at 1.808 MeV.

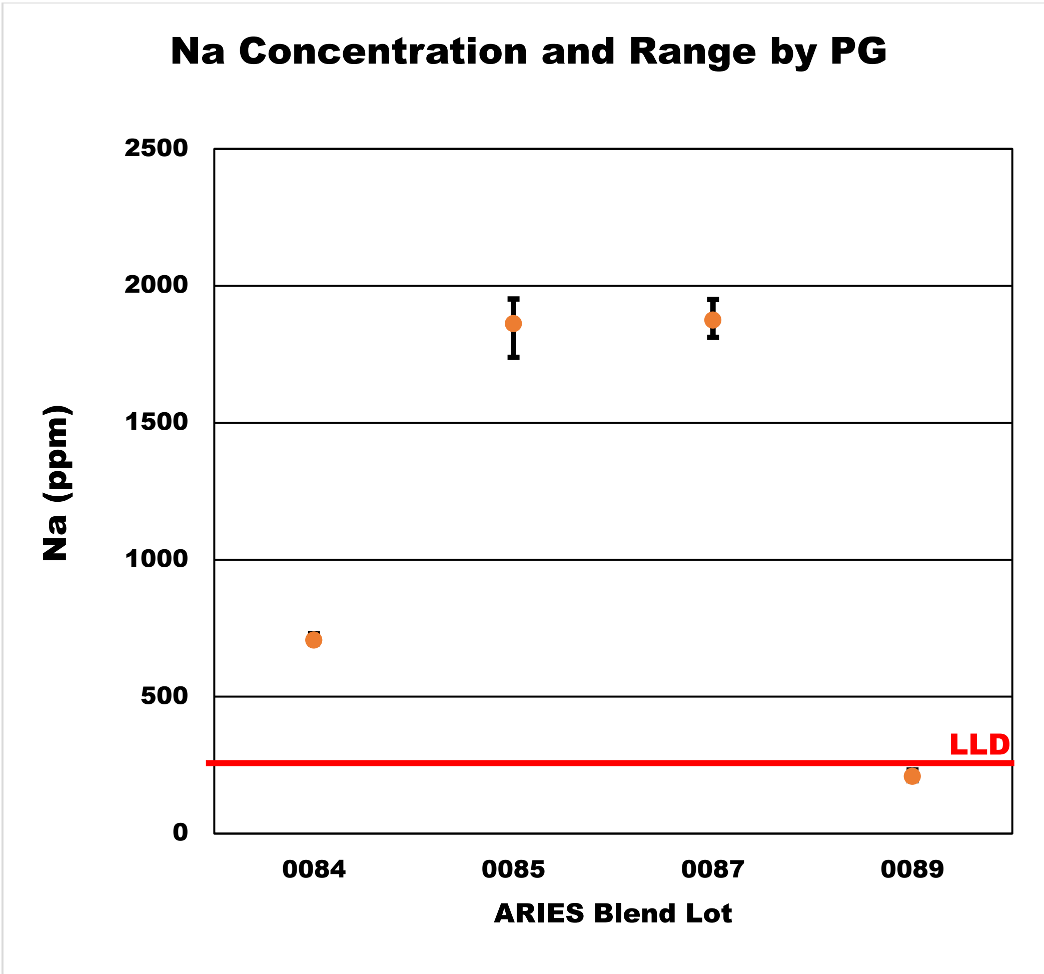

Figure 10. Comparison of sodium measurements by PG and analytical chemistry. Error bars indicate the range of the PG measurements for the individual containers. Analytical chemistry was not available for BL 78 through 89.

3.3.4 *Results for Other Elements (phosphorus and aluminum)*

Phosphorus was detected in all three containers in BL 75. The source of this impurity is likely the swap material feed, and the reason for its presence is not known. The average concentration for the three containers with phosphorus was 1704 ppm, and the concentrations of the individual containers ranged from 1361 to 2022 ppm. These values are all higher than the reported analytical chemistry result of 760 ppm. The differences are attributed to the large uncertainty in the phosphorus calibration.

Aluminum was detected in one container in BL 87. The source of this impurity is likely the swap material feed. The concentration reported by PG was 853 ppm. This concentration is below the LLD. The aluminum signal was too weak to be observed in the other containers in BL 87.

3.4 Recommendations for the Use of PG Analysis for ARIES Materials

New calibration equations have been developed to determine the concentrations of a set of light elements in plutonium oxide using PG analysis. LLDs for these elements in high-purity and impure plutonium oxides are reported in Table 3-1 for 60 and 600 minute counting times, and parameters for calculating the LLDs are for any counting time are given in Appendix A. PG analysis can indicate whether lithium and boron are present above the LLD, but the concentrations cannot be determined. The LLDs were determined from a statistical analysis, so while it is possible to detect elements below the reported LLD, the results are not reliable. This method is applicable to Pu oxides in any container provided that the wall thickness is known. The Prompt Gamma Analysis Software allows the user to specify a wall thickness if the desired container is not available in the container selection menu. PG analysis can also detect light elements in impure metals on a qualitative basis. However, it is unlikely that the impurities would achieve the necessary mixing required for reliable detection, so PG analysis of metals should be used as a screening tool only.

Obtaining the correct results from PG analysis requires that the parameter sets in the ISP Database maintained by SRS and in the Prompt Gamma Analysis Software. The ISP Database has a query that calculates the concentrations based on these calibration parameters. Therefore, it is recommended that the database query "qryPCDPromptGamma" is updated with the new calibration parameters for all elements except for fluorine based on the 0.891 MeV peak (see Section 3.5).

Operators should ensure that the Prompt Gamma Analysis Software v4.7g is the currently installed software package and update the parameter sets to use the new parameters described in this paper to avoid conflict with the results provided by the database. It is recommended that changes be made to the following data files:

- Updates to "PkParamLst.xls" located in "C:\PGProgs\MakeTable\ and C:\PGProgs\SpecAnalyzer\"
  - Enter β_C from Table __ in PkParamLst.xls, column R
  - Enter the LLD_{60} from Table__ in PkParamLst.xls, column P

It should be noted that the file "PkParamLst.xls" is a tab-delimited text file that opens in Microsoft® Excel®.

Use of the fluorine peak at 1.274 MeV requires an interference correction for magnesium. The Prompt Gamma Analysis Software does not perform this correction automatically; therefore, the calculated concentrations provided in the custom output file may be biased high. A similar situation exists for the magnesium peak at 1.779 MeV, which has a sodium interference. Therefore, it is recommended that the PGA Table Generator function is used to export the count rates or the normalized peak areas into a spreadsheet, and that a spreadsheet calculation is used to correct the 1.779 MeV and 1.274 MeV peak data according to Eq. (16) prior to calculating the impurity concentrations for magnesium and fluorine.

PG analysis can be applied to ARIES oxide materials to determine whether certain elements meet the 9977 OTC limits. Table 3-3 shows the detectable elements and minimum live time required to ensure that an element is below the 9977 OTC limit based on the 90% confidence interval for the LLD. As shown by the green shading, PG analysis would be feasible for determining whether lithium, beryllium, fluorine, and sodium are below the 9977 OTC limits. The minimum detector live time is 0.9 hours for high-purity ARIES product oxide and 4.2 hours for other impure oxides such as those with swap material feed. It is recommended that the detection system is set to count based on the desired live time rather than the total count time. Beryllium is highlighted in yellow in Table 3-3 because a minimum of 4.2 hour live time is required if the material originated in an impure feed rather than high-purity ARIES product oxide. Shorter count times may be used for beryllium under the following conditions:

- The material is known by process history to be high-purity ARIES product oxide or similar and no other impurities are detected by PG analysis during a 60 minute count; OR
- Beryllium is detected prior to counting for 4.2 hours.

Table 3-3. Minimum live times for verification of 9977 OTC limits.
Green shading indicates use of PG is feasible. Red shading indicates use of PG is not feasible. Yellow shading indicates caution for use of the correct calibration equation for the material being analyzed.

Element	Peak [MeV]	Applicability	Conc. Eqn. (Y/N)	9977 OTC Limit [ppm] [5]	Minimum Live Time[a] [hr]
Lithium	0.478	All oxides	N	440	0.7[b]
Beryllium	4.439	Any impure oxide	Y	88	4.2
		High-purity ARIES product oxide	Y	88	0.1
Boron	3.684	All oxides	N	440	55.1[b]
Fluorine	0.891	All oxides	Y	220	42.1
	1.274	All oxides	Y	220	0.2[c]
Sodium	1.808	All oxides	Y	264	0.9
Magnesium	1.779	All oxides	Y	440	37.2
	2.028	All oxides	Y	440	58.3
Aluminum	2.236	All oxides	Y	132	96.0
Phosphorus	2.127	All oxides	Y	100[d]	>100
Chlorine	2.167	All oxides	Y	100[d]	>100
Potassium	1.524	All oxides	Y	100[d]	>100

a. Includes uncertainty based on 90% confidence intervals Eq. (14)
b. LLD estimated based on limited data set
c. Requires correction for magnesium interference
d. 9977 OTC limit of 100 ppm each inorganic material impurity

Currently, the use of PG analysis is not recommended for verification of 9977 OTC limits for boron, magnesium, aluminum, phosphorus, chlorine, and potassium based on the minimum counting times required. Therefore, PG analysis would need to be paired with another method of characterization in order to verify all of the 9977 OTC limits. However, if the 9977 OTC limits were to increase in the future, such as through an amendment, PG analysis could be considered.

Few analytical chemistry and PG data exist for lithium and boron in plutonium oxide, and it is recommended that any materials found to have these impurities by PG be sampled for analytical chemistry. It is possible that these elements may have higher sensitivities and, therefore, lower LLDs when they are present in high-purity oxide. If sufficient data are obtained, calibrations could be developed to calculate the impurity concentrations of those elements.

3.5 Impact to Existing Container Data in the ISP Database

Fluorine concentrations are used in the surveillance binning of containers, and containers with 0.8 wt% fluorine or greater are placed in the pressure and corrosion bin. Based on the 2015 calibration, 316 items have fluorine greater than 0.8 wt%. Using the new calibration the fluorine concentration drops by 0.004 wt% resulting in four of the original items having less than 0.8 wt% fluorine. One of the containers has chlorine detected, so the overall impact to the surveillance binning is that three containers previously identified as having 0.8 wt% or greater fluorine are now identified as having 0.793 wt% or greater. Comparing the new calibration parameters for the 0.891 MeV peak in Appendix A with the 2015 calibration parameters for the 0.891 MeV peak shows a negligible change to both the sensitivity and the uncertainty of the measurements. Therefore, it is recommended that no changes are made to the calibration parameters for the 0.891 MeV peak in either the software or the ISP database.

The 1.274 MeV peak calibration provides a separate measurement for fluorine that is an order of magnitude more sensitive than the measurement based on the 0.891 MeV peak. Therefore some containers have more than one result for fluorine, and an additional 1,408 containers now have a reported concentration for fluorine where it was previously not detected. The containers that have two results should rely on the measurement based on the 0.891 MeV peak for consistency with past measurements. Differences between the results obtained from the 1.274 MeV peak and the 0.891 MeV peak vary from container to container. A regression analysis of the fluorine measurements from the 1.274 MeV peak as a function of the fluorine measurements from the 0.891 MeV peak has a slope of 1 as shown in Figure 11, which indicates that the differences are random. Possible reasons for the differences include counting errors and uncertainties introduced in the interference corrections performed on the 1.274 MeV peak.

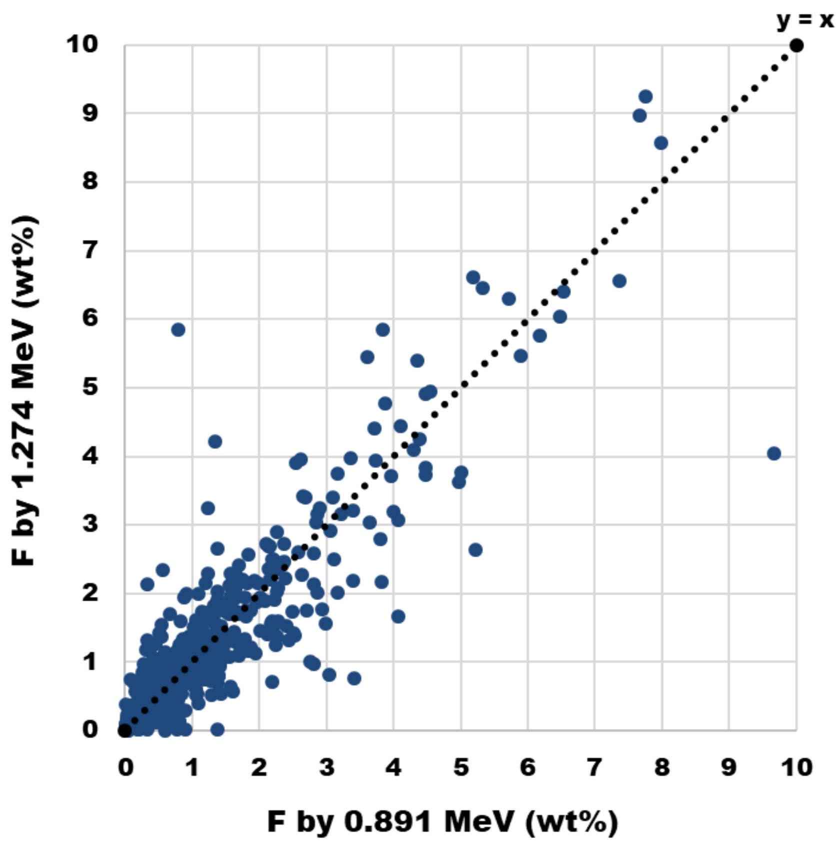

Figure 11. Comparison of fluorine concentrations determined from the 1.274 MeV peak to the 0.891 MeV peak.

4 Conclusion

PG analysis was performed on 265 ARIES 3013 containers packaged with oxide from BL 1 through 89. Beryllium was detected in 39 containers in concentrations ranging from 20 to 700 ppm. Fluorine was detected in 23 containers in concentrations ranging from 10 to 600 ppm. Chorine was detected in 9 containers all from BL 84, 85, and 87. The chlorine concentration ranged from 3,000 to 11,000 ppm.

The PG calibration equations used to calculate the concentrations of light element impurities in plutonium oxide have been updated with new data, and new LLDs have been obtained for each of the elements using WLS models of PG and analytical chemistry data. A new calibration was developed for fluorine based on the 1.274 MeV peak, which is an order of magnitude more sensitive than calibration based on the 0.891 MeV peak. An additional calibration was developed for beryllium based on the higher sensitivity of the beryllium signal observed in high-purity ARIES oxide. LLDs for the sensitive elements were determined as a function of detector live time, along with the minimum live times required to meet the limits of the 9977 OTC. Based on this analysis, it was determined that detection of lithium, beryllium, fluorine, and sodium would be feasible in plutonium oxide with minimum live times ranging from 0.9 to 4.2 hours. Although PG can detect boron, magnesium, aluminum, phosphorus, chlorine, and potassium, the minimum live times required to meet 9977 OTC limits exceed 30 hours.

5 References

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Appendix A: Parameters for Calculating Concentration, LLD, and Uncertainties

Table A-1.Concentration C_C calculation and uncertainty parameters.

Eq.	**Applicability**	***n***	***df***	β_C [ppm^{-1}]	***se***	Σw_i	$\Sigma w_i C_i^2$ [ppm^2]	$(\Sigma w_i C_i)^2$ [ppm^2]	$\overline{PG_W}$	***t(df,0.05)***
$C_{C,Al}$	All	51	50	7.379E-07	3.999E-05	2.361E-02	4.517E+05	51	2.152E-03	1.6759
$C_{C,Be}$	Impure Oxide	36	35	1.510E-05	3.352E-04	1.195E-01	4.874E+04	36	7.404E-03	1.6896
$C_{C,Cl}$	All	125	124	9.304E-08	7.053E-06	8.935E-03	8.228E+06	125	1.555E-03	1.6572
$C_{C,F}$	All	38	37	1.092E-06	6.890E-05	2.187E-02	9.088E+05	38	2.656E-03	1.6871
$C_{C,Mg}$	All	223	222	3.613E-07	4.262E-05	7.745E-02	1.683E+07	223	2.543E-03	1.6517
$C_{C,Mg,2}$	All	117	116	7.608E-08	8.535E-06	5.604E-03	1.602E+07	117	2.089E-03	1.6581
$C_{C,P}$	All	16	15	3.708E-07	1.188E-05	1.167E-02	9.480E+04	16	6.624E-04	1.7531
$C_{C,K}$	All	91	90	7.226E-08	4.415E-06	3.027E-03	3.429E+06	91	2.306E-03	1.6620
$C_{C,Na}$	All	186	185	3.876E-06	1.598E-04	3.689E-01	2.680E+06	186	3.049E-03	1.6531
New Calibration Equations										
$C_{C,Be,2}$	High-purity ARIES	7	6	9.174E-05	2.016E-04	1.646E-01	4.808E+02	7	4.223E-03	1.9432
$C_{C,F,2}$	All	58	57	1.079E-05	6.116E-04	1.976E-01	9.133E+05	58	6.386E-03	1.6720

Table A-2.LLD C_L calculation and uncertainty parameters.

Eq.	Applicability	n	df	β_L [ppm^{-1}]	se	Σw_i	$\Sigma w_i C_i^2$ [ppm^2]	$(\Sigma w_i C_i)^2$ [ppm^2]	$\overline{PG_W}$	$t(df,0.05)$
$C_{L,Al}$	All	61	60	1.822E-05	3.561E-04	1.259E-01	5.086E+04	61	1.228E-02	1.6706
$C_{L,Be}$	Impure Oxide	29	28	1.303E-04	7.925E-04	2.992E-01	4.040E+03	29	1.563E-02	1.7011
$C_{L,Cl}$	All	141	140	2.501E-06	9.486E-05	3.494E-02	8.712E+05	141	1.209E-02	1.6558
$C_{L,F}$	All	46	45	1.652E-05	2.906E-04	7.752E-02	4.524E+04	46	1.254E-02	1.6794
$C_{L,Mg}$	All	171	170	8.780E-06	1.803E-04	1.485E-01	2.795E+05	171	1.213E-02	1.6539
$C_{L,Mg,2}$	All	52	51	7.016E-06	2.104E-04	4.846E-02	9.112E+04	52	1.072E-02	1.6753
$C_{L,P}$	All	13	12	9.060E-06	1.626E-04	2.097E-02	1.575E+04	13	7.935E-03	1.7823
$C_{L,K}$	All	103	102	7.541E-07	7.467E-05	8.502E-03	2.098E+06	103	1.306E-02	1.6599
$C_{L,Na}$	All	206	205	9.222E-05	7.351E-04	1.706E+00	3.629E+04	206	1.393E-02	1.6523
$C_{L,Be,2}$	High-purity ARIES	22	21	9.429E-04	1.429E-03	1.605E+00	5.508E+02	22	1.522E-02	1.7207
$C_{L,F,2}$	All	77	76	2.326E-04	1.102E-03	1.762E+00	6.383E+03	77	1.301E-02	1.6652

Appendix B: ARIES Prompt Gamma Results BL 1 through 89

Table B-1.Prompt gamma results for ARIES containers in BL 1 thorough 89.

BL No.	3013 ID	Spectrum File Name	Date Measured	Live Time	Al [ppm]	Be [ppm]	Cl [ppm]	F [ppm]	Mg [ppm]	P [ppm]	K [ppm]	Na [ppm]	F (HS) [ppm]	Mg (LS) [ppm]	Li (LLD) [ppm]	B (LLD) [ppm]	Be (HS) [ppm]	PG Category
0001	A000836	A000836.chn	02-Aug-10	1857	< 1274	< 178	< 9280	< 1405	< 2643	< 2561	< 30772	< 252	< 100	< 3307	< 362	< 6433	< 25	PGNoImp
0001	A000824	A000824.chn	29-Jul-10	3000	< 1002	< 140	< 7301	< 1105	< 2079	< 2015	< 24211	< 198	< 78	< 2602	< 285	< 5061	< 19	PGNoImp
0002	A000616	A000616.chn	18-Aug-10	1843	< 1278	< 179	< 9315	< 1410	< 2653	< 2571	< 30889	< 253	< 100	< 3320	< 363	< 6457	< 25	PGNoImp
0002	A000847	A000847.chn	19-Aug-10	1902	< 1258	< 176	< 9170	< 1388	< 2612	< 2531	< 30406	< 249	< 99	< 3268	< 358	< 6356	< 24	PGNoImp
0002	A000648	A000648.chn	18-Aug-10	1734	< 1318	< 184	< 9604	< 1454	< 2735	< 2651	< 31845	< 260	< 103	< 3423	< 375	< 6657	< 25	PGNoImp
0003	A000595	A000595.chn	24-Aug-10	1770	< 1304	< 182	< 9505	< 1439	< 2707	< 2624	< 31520	< 258	< 102	< 3388	< 371	< 6589	< 25	PGNoImp
0003	A000553	A000553.chn	19-Aug-10	2054	< 1211	< 169	< 8824	< 1336	< 2513	< 2435	< 29259	< 239	< 95	< 3145	< 344	< 6116	< 23	PGNoImp
0003	A000598	A000598.chn	31-Aug-10	2221	< 1165	< 163	< 8486	< 1284	< 2417	< 2342	< 28138	< 230	< 91	< 3024	< 331	< 5882	< 23	PGNoImp
0004	A000584	A000584.chn	13-Sep-10	2082	< 1203	< 168	< 8764	< 1327	< 2496	< 2419	< 29062	< 238	< 94	< 3124	< 342	< 6075	< 23	PGNoImp
0004	A000546	A000546.chn	14-Sep-10	2157	< 1182	< 165	< 8611	< 1303	< 2452	< 2377	< 28552	< 233	< 93	< 3069	< 336	< 5969	< 23	PGNoImp
0004	A000317	A000317.chn	14-Sep-10	2173	< 1177	< 165	< 8579	< 1298	< 2443	< 2368	< 28447	250	< 92	< 3057	< 335	< 5947	< 23	PGMisc
0005	A000544	A000544.chn	13-Dec-10	2181	< 1175	< 164	< 8563	< 1296	< 2439	< 2364	< 28395	< 232	< 92	< 3052	< 334	< 5936	< 23	PGNoImp
0005	A000339	A000339.chn	13-Dec-10	2014	< 1223	< 171	< 8911	< 1349	< 2538	< 2460	< 29549	< 242	< 96	< 3176	< 348	< 6177	< 24	PGNoImp
0005	A000314	A000314.chn	09-Dec-10	2002	< 1227	< 171	< 8938	< 1353	< 2545	< 2467	< 29637	< 242	< 96	< 3185	< 349	< 6195	< 24	PGNoImp
0006	A000486	A000486.chn	26-Jan-11	2293	< 1146	218	< 8351	< 1264	< 2378	< 2305	< 27693	287	< 90	< 2976	< 326	< 5789	36	PGMisc
0006	A000574	A000574.chn	26-Jan-11	1820	< 1286	229	< 9374	< 1419	< 2670	< 2587	< 31084	< 254	< 101	< 3341	< 366	< 6498	38	PGMisc
0006	A000688	A000688.chn	26-Jan-11	1977	< 1234	163	< 8994	< 1361	< 2562	< 2482	< 29824	< 244	< 97	< 3205	< 351	< 6234	27	PGMisc
0007	A000328	A000328.chn	26-Jan-11	2206	< 1168	< 163	< 8514	< 1289	< 2425	< 2350	< 28233	< 231	< 92	< 3035	< 332	< 5902	< 23	PGNoImp
0007	A000694	A000694.chn	31-Jan-11	2048	< 1213	< 170	< 8837	< 1338	< 2517	< 2439	< 29302	< 240	< 95	< 3149	< 345	< 6125	< 24	PGNoImp
0007	A000692	A000692.chn	31-Jan-11	1905	< 1257	< 176	< 9162	< 1387	< 2609	< 2529	< 30382	< 248	< 98	< 3265	< 357	< 6351	< 24	PGNoImp
0008	A000619	A000619.chn	23-Feb-11	1976	< 1235	< 173	< 8996	< 1362	< 2562	< 2483	< 29831	< 244	< 97	< 3206	< 351	< 6236	< 24	PGNoImp
0008	A000638	A000638.chn	23-Feb-11	1967	< 1237	< 173	< 9017	< 1365	< 2568	< 2489	< 29900	263	< 97	< 3214	< 352	< 6250	< 24	PGMisc
0008	A000466	A000466.chn	23-Feb-11	1905	< 1257	< 176	< 9162	< 1387	< 2609	< 2529	< 30382	< 248	< 98	< 3265	< 357	< 6351	< 24	PGNoImp
0009	A000802	A000802.chn	08-Mar-11	1959	< 1240	< 173	< 9035	< 1368	< 2573	< 2494	< 29961	< 245	< 97	< 3220	< 352	< 6263	< 24	PGNoImp
0009	A000818	A000818.chn	08-Mar-11	2131	< 1189	< 166	< 8663	< 1311	< 2467	< 2391	< 28726	< 235	< 93	< 3087	< 338	< 6005	< 23	PGNoImp

Appendix B: ARIES Prompt Gamma Results BL 1 through 89

BL No.	3013 ID	Spectrum File Name	Date Measured	Live Time	Al [ppm]	Be [ppm]	Cl [ppm]	F [ppm]	Mg [ppm]	P [ppm]	K [ppm]	Na [ppm]	F (HS) [ppm]	Mg (LS) [ppm]	Li (LLD) [ppm]	B (LLD) [ppm]	Be (HS) [ppm]	PG Category
0009	A000840	A000840.chn	09-Mar-11	2153	< 1183	< 165	< 8619	< 1304	< 2455	< 2379	< 28579	< 234	< 93	< 3072	< 336	< 5974	< 23	PGNoImp
0010	A000348	A000348.chn	22-Mar-11	1872	< 1268	< 177	< 9243	< 1399	< 2632	< 2551	< 30649	< 251	< 99	< 3294	< 361	< 6407	< 24	PGNoImp
0010	A000341	A000341.chn	22-Mar-11	2059	< 1209	< 169	< 8813	< 1334	< 2510	< 2433	< 29224	< 239	< 95	< 3141	< 344	< 6109	< 23	PGNoImp
0010	A000835	A000835.chn	22-Mar-11	1958	< 1240	< 173	< 9038	< 1368	< 2574	< 2494	< 29968	< 245	< 97	< 3221	< 353	< 6265	< 24	PGNoImp
0011	A000608	A000608.chn	07-Apr-11	1883	< 1265	< 177	< 9216	< 1395	< 2625	< 2544	< 30559	< 250	< 99	< 3284	< 360	< 6388	< 24	PGNoImp
0011	A000683	A000683.chn	07-Apr-11	1945	< 1244	< 174	< 9068	< 1372	< 2583	< 2503	< 30068	< 246	< 97	< 3232	< 354	< 6285	< 24	PGNoImp
0011	A000636	A000636.chn	07-Apr-11	1934	< 1248	< 174	< 9094	< 1376	< 2590	< 2510	< 30154	< 247	< 98	< 3241	< 355	< 6303	< 24	PGNoImp
0012	A000614	A000614.chn	13-Apr-11	2352	< 1132	< 158	< 8246	< 1248	< 2348	< 2276	< 27343	< 224	< 89	< 2939	< 322	< 5716	< 22	PGNoImp
0012	A000635	A000635.chn	14-Apr-11	2186	< 1174	< 164	< 8553	< 1295	< 2436	< 2361	< 28362	< 232	< 92	< 3048	< 334	< 5929	< 23	PGNoImp
0012	A000691	A000691.chn	14-Apr-11	1940	< 1246	< 174	< 9079	< 1374	< 2586	< 2506	< 30107	< 246	< 98	< 3236	< 354	< 6294	< 24	PGNoImp
0013	A000663	A000663.chn	27-Apr-11	2155	< 1182	< 165	< 8615	< 1304	< 2453	< 2378	< 28566	< 234	< 93	< 3070	< 336	< 5971	< 23	PGNoImp
0013	A000603	A000603.chn	27-Apr-11	2124	< 1191	< 166	< 8677	< 1313	< 2471	< 2395	< 28773	< 235	< 93	< 3093	< 338	< 6015	< 23	PGNoImp
0013	A000837	A000837.chn	27-Apr-11	2025	< 1220	< 171	< 8887	< 1345	< 2531	< 2453	< 29468	< 241	< 96	< 3167	< 347	< 6160	< 24	PGNoImp
0014	A000687	A000687.chn	03-May-11	1810	< 1290	< 180	< 9400	< 1423	< 2677	< 2594	< 31169	< 255	< 101	< 3350	< 367	< 6516	< 25	PGNoImp
0014	A000602	A000602.chn	03-May-11	2187	< 1174	< 164	< 8551	< 1294	< 2435	< 2360	< 28356	< 232	< 92	< 3048	< 334	< 5927	< 23	PGNoImp
0014	A000689	A000689.chn	03-May-11	1754	< 1310	< 183	< 9549	< 1445	< 2720	< 2636	< 31663	< 259	< 103	< 3403	< 372	< 6619	< 25	PGNoImp
0015	A000697	A000697.chn	17-May-11	1894	< 1261	< 176	< 9189	< 1391	< 2617	< 2536	< 30470	< 249	< 99	< 3275	< 358	< 6369	< 24	PGNoImp
0015	A000696	A000696.chn	17-May-11	1837	< 1280	< 179	< 9331	< 1412	< 2657	< 2575	< 30939	< 253	< 100	< 3325	< 364	< 6468	< 25	PGNoImp
0015	A000698	A000698.chn	31-Aug-11	1997	< 1228	< 172	< 8949	< 1354	< 2549	< 2470	< 29674	< 243	< 96	< 3189	< 349	< 6203	< 24	PGNoImp
0016	H003183	H003183.chn	20-Jun-11	1998	< 1228	< 172	< 8947	< 1354	< 2548	< 2469	< 29667	< 243	< 96	< 3189	< 349	< 6201	< 24	PGNoImp
0016	H003144	H003144.chn	20-Jun-11	2001	< 1227	< 172	< 8940	< 1353	< 2546	< 2468	< 29644	< 242	< 96	< 3186	< 349	< 6197	< 24	PGNoImp
0016	H003134	H003134.chn	15-Jun-11	2121	< 1192	< 167	< 8683	< 1314	< 2473	< 2397	< 28794	< 235	< 93	< 3095	< 339	< 6019	< 23	PGNoImp
0017	H003139	H003139.chn	19-Jul-11	1951	< 1242	< 174	< 9054	< 1370	< 2579	< 2499	< 30022	< 246	< 97	< 3227	< 353	< 6276	< 24	PGNoImp
0017	H003135	H003135.chn	19-Jul-11	1888	< 1263	< 177	< 9204	< 1393	< 2621	< 2540	< 30519	< 250	< 99	< 3280	< 359	< 6380	< 24	PGNoImp
0017	H003228	H003228.chn	19-Jul-11	2173	< 1177	< 165	< 8579	< 1298	< 2443	< 2368	< 28447	< 233	< 92	< 3057	< 335	< 5947	< 23	PGNoImp
0018	H003143	H003143.chn	11-Jul-11	2019	< 1221	< 171	< 8900	< 1347	< 2535	< 2457	< 29512	< 241	< 96	< 3172	< 347	< 6169	< 24	PGNoImp
0018	H003192	H003192.chn	11-Jul-11	2058	< 1210	< 169	< 8815	< 1334	< 2511	< 2433	< 29231	< 239	< 95	< 3142	< 344	< 6110	< 23	PGNoImp
0018	H003137	H003137.chn	11-Jul-11	1971	< 1236	< 173	< 9008	< 1363	< 2565	< 2486	< 29869	< 244	< 97	< 3210	< 351	< 6244	< 24	PGNoImp
0019	H003212	H003212.chn	03-Aug-11	1944	< 1245	< 174	< 9070	< 1373	< 2583	< 2503	< 30076	< 246	< 98	< 3233	< 354	< 6287	< 24	PGNoImp
0019	H003223	H003223.chn	02-Aug-11	1824	< 1285	< 180	< 9364	< 1417	< 2667	< 2584	< 31050	< 254	< 101	< 3337	< 365	< 6491	< 25	PGNoImp

BL No.	3013 ID	Spectrum File Name	Date Measured	Live Time	Al [ppm]	Be [ppm]	Cl [ppm]	F [ppm]	Mg [ppm]	P [ppm]	K [ppm]	Na [ppm]	F (HS) [ppm]	Mg (LS) [ppm]	Li (LLD) [ppm]	B (LLD) [ppm]	Be (HS) [ppm]	PG Category
0019	H003237	H003237.chn	03-Aug-11	1976	< 1235	< 173	< 8996	< 1362	< 2562	< 2483	< 29831	< 244	< 97	< 3206	< 351	< 6236	< 24	PGNoImp
0020	H003194	H003194.chn	11-Aug-11	2109	< 1195	< 167	< 8708	< 1318	< 2480	< 2404	< 28875	< 236	< 94	< 3104	< 340	< 6036	< 23	PGNoImp
0020	H003133	H003133.chn	11-Aug-11	2111	< 1194	< 167	< 8704	< 1317	< 2479	< 2402	< 28862	< 236	< 94	< 3102	< 340	< 6033	< 23	PGNoImp
0020	H003138	H003138.chn	11-Aug-11	2071	< 1206	< 169	< 8788	< 1330	< 2503	< 2425	< 29139	< 238	< 94	< 3132	< 343	< 6091	< 23	PGNoImp
0021	H003141	H003141.chn	31-Aug-11	2129	< 1189	< 166	< 8667	< 1312	< 2468	< 2392	< 28740	< 235	< 93	< 3089	< 338	< 6008	< 23	PGNoImp
0021	H003136	H003136.chn	31-Aug-11	2148	< 1184	< 166	< 8629	< 1306	< 2457	< 2382	< 28612	< 234	< 93	< 3075	< 337	< 5981	< 23	PGNoImp
0022	H003239	H003239.chn	15-Feb-12	1867	< 1270	288	< 9255	< 1401	< 2636	< 2555	< 30690	< 251	< 99	< 3299	< 361	< 6415	47	PGMisc
0022	H003016	H003016.chn	15-Feb-12	2274	< 1151	278	< 8386	< 1269	< 2388	< 2315	< 27808	< 227	< 90	< 2989	< 327	< 5813	46	PGMisc
0022	H003171	H003171.chn	15-Feb-12	1822	< 1286	272	< 9369	< 1418	< 2668	< 2586	< 31067	< 254	< 101	< 3339	< 365	< 6494	45	PGMisc
0023	H003188	H003188.chn	16-Feb-12	2084	< 1202	< 168	< 8760	< 1326	< 2495	< 2418	< 29048	< 238	< 94	< 3122	< 342	< 6072	< 23	PGNoImp
0023	H003229	H003229.chn	16-Feb-12	1982	< 1233	< 172	< 8983	< 1360	< 2558	< 2479	< 29786	< 244	< 97	< 3201	< 350	< 6226	< 24	PGNoImp
0023	H003013	H003013.chn	16-Feb-12	1931	< 1249	< 175	< 9101	< 1377	< 2592	< 2512	< 30177	< 247	< 98	< 3243	< 355	< 6308	< 24	PGNoImp
0024	H003198	H003198.chn	05-Mar-12	1983	< 1232	< 172	< 8980	< 1359	< 2558	< 2479	< 29779	< 244	< 97	< 3201	< 350	< 6225	< 24	PGNoImp
0024	H003019	H003019.chn	05-Mar-12	2005	< 1226	< 171	< 8931	< 1352	< 2544	< 2465	< 29615	< 242	< 96	< 3183	< 348	< 6191	< 24	PGNoImp
0024	H003246	H003246.chn	05-Mar-12	2018	< 1222	< 171	< 8902	< 1347	< 2535	< 2457	< 29519	< 241	< 96	< 3173	< 347	< 6171	< 24	PGNoImp
0025	H003190	H003190.chn	15-Mar-12	1906	< 1257	318	< 9160	< 1386	< 2609	< 2528	< 30374	< 248	< 98	< 3265	< 357	< 6349	52	PGMisc
0025	H003238	H003238.chn	15-Mar-12	2126	< 1190	378	< 8673	< 1313	< 2470	< 2394	< 28760	< 235	< 93	< 3091	< 338	< 6012	62	PGMisc
0025	H003234	H003234.chn	21-Mar-12	2025	< 1220	389	< 8887	< 1345	< 2531	< 2453	< 29468	< 241	< 96	< 3167	< 347	< 6160	64	PGMisc
0026	H002964	H002964.chn	21-Mar-12	2047	< 1213	< 170	< 8839	< 1338	< 2517	< 2440	< 29309	< 240	< 95	< 3150	< 345	< 6127	< 24	PGNoImp
0026	H003232	H003232.chn	22-Mar-12	1947	< 1244	< 174	< 9063	< 1372	< 2581	< 2502	< 30053	< 246	< 97	< 3230	< 354	< 6282	< 24	PGNoImp
0026	H003193	H003193.chn	21-Mar-12	1976	< 1235	< 173	< 8996	< 1362	< 2562	< 2483	< 29831	< 244	< 97	< 3206	< 351	< 6236	< 24	PGNoImp
0027	H002937	H002937.chn	27-Mar-12	2036	< 1216	< 170	< 8863	< 1341	< 2524	< 2446	< 29389	< 240	< 95	< 3159	< 346	< 6143	< 24	PGNoImp
0027	H002919	H002919.chn	27-Mar-12	1986	< 1231	< 172	< 8974	< 1358	< 2556	< 2477	< 29756	< 243	< 96	< 3198	< 350	< 6220	< 24	PGNoImp
0027	H002902	H002902.chn	27-Mar-12	1945	< 1244	< 174	< 9068	< 1372	< 2583	< 2503	< 30068	< 246	< 97	< 3232	< 354	< 6285	< 24	PGNoImp
0028	H002965	H002965.chn	17-Apr-12	2087	< 1201	< 168	< 8754	< 1325	< 2493	< 2416	< 29027	< 237	< 94	< 3120	< 341	< 6068	< 23	PGNoImp
0028	H002974	H002974.chn	17-Apr-12	2054	< 1211	< 169	< 8824	< 1336	< 2513	< 2435	< 29259	< 239	< 95	< 3145	< 344	< 6116	< 23	PGNoImp
0028	H002960	H002960.chn	12-Apr-12	2090	< 1200	< 168	< 8748	< 1324	< 2491	< 2414	< 29006	< 237	< 94	< 3118	< 341	< 6063	< 23	PGNoImp
0029	H002909	H002909.chn	11-Apr-12	2083	< 1202	< 168	< 8762	< 1326	< 2496	< 2418	< 29055	< 238	< 94	< 3123	< 342	< 6074	< 23	PGNoImp
0029	H002896	H002896.chn	12-Apr-12	2190	< 1173	< 164	< 8546	< 1293	< 2434	< 2359	< 28336	< 232	< 92	< 3046	< 333	< 5923	< 23	PGNoImp
0029	H002906	H002906.chn	11-Apr-12	2088	< 1201	< 168	< 8752	< 1325	< 2493	< 2416	< 29020	< 237	< 94	< 3119	< 341	< 6066	< 23	PGNoImp

Appendix B: ARIES Prompt Gamma Results BL 1 through 89

BL No.	3013 ID	Spectrum File Name	Date Measured	Live Time	Al [ppm]	Be [ppm]	Cl [ppm]	F [ppm]	Mg [ppm]	P [ppm]	K [ppm]	Na [ppm]	F (HS) [ppm]	Mg (LS) [ppm]	Li (LLD) [ppm]	B (LLD) [ppm]	Be (HS) [ppm]	PG Category
0030	H002925	H002925.chn	02-May-12	2087	< 1201	< 168	< 8754	< 1325	< 2493	< 2416	< 29027	< 237	< 94	< 3120	< 341	< 6068	< 23	PGNoImp
0030	H002947	H002947.chn	03-May-12	2005	< 1226	< 171	< 8931	< 1352	< 2544	< 2465	< 29615	< 242	< 96	< 3183	< 348	< 6191	< 24	PGNoImp
0030	H002935	H002935.chn	03-May-12	2150	< 1184	< 165	< 8625	< 1305	< 2456	< 2380	< 28599	< 234	< 93	< 3074	< 336	< 5978	< 23	PGNoImp
0031	H002929	H002929.chn	08-May-12	2068	< 1207	< 169	< 8794	< 1331	< 2505	< 2427	< 29160	< 238	< 95	< 3134	< 343	< 6096	< 23	PGNoImp
0031	H002948	H002948.chn	10-May-12	2042	< 1214	< 170	< 8850	< 1339	< 2520	< 2443	< 29345	< 240	< 95	< 3154	< 345	< 6134	< 24	PGNoImp
0031	H002978	H002978.chn	10-May-12	2078	< 1204	< 168	< 8773	< 1328	< 2499	< 2421	< 29090	372	< 94	< 3127	< 342	< 6081	< 23	PGMisc
0032	H003090	H003090.chn	13-Jun-12	2106	< 1196	< 167	< 8714	< 1319	< 2482	< 2405	< 28896	< 236	< 94	< 3106	< 340	< 6040	< 23	PGNoImp
0032	H002966	H002966.chn	13-Jun-12	2120	< 1192	< 167	< 8685	< 1315	< 2474	< 2397	< 28800	< 236	< 93	< 3095	< 339	< 6020	< 23	PGNoImp
0032	H002903	H002903.chn	13-Jun-12	2143	< 1186	< 166	< 8639	< 1308	< 2460	< 2384	< 28645	< 234	< 93	< 3079	< 337	< 5988	< 23	PGNoImp
0033	H002904	20210121_165445_h002904-pg-20hr.chn	21-Jan-21	48470	< 249	101	< 1816	< 275	< 517	< 501	< 6023	< 49	9	< 647	< 71	< 1259	17	PGFLo
0033	H002907	H002907.chn	12-Jun-12	1926	< 1251	< 175	< 9112	< 1379	< 2595	< 2515	< 30216	< 247	< 98	< 3248	< 355	< 6316	< 24	PGNoImp
0033	H002923	H002923.chn	12-Jun-12	2090	< 1200	< 168	< 8748	< 1324	< 2491	< 2414	< 29006	< 237	< 94	< 3118	< 341	< 6063	< 23	PGNoImp
0034	H002924	H002924.chn	12-Jun-12	2141	< 1186	319	< 8643	< 1308	< 2461	< 2385	< 28659	< 234	< 93	< 3080	< 337	< 5991	53	PGMisc
0034	H002944	H002944.chn	20-Jun-12	2133	< 1188	317	< 8659	< 1311	< 2466	< 2390	< 28713	< 235	< 93	< 3086	< 338	< 6002	52	PGMisc
0034	H002911	H002911.chn	20-Jun-12	2110	< 1195	343	< 8706	< 1318	< 2479	< 2403	< 28869	< 236	< 94	< 3103	< 340	< 6035	56	PGMisc
0035	H002951	H002951.chn	09-Jul-12	2013	< 1223	< 171	< 8913	< 1349	< 2539	< 2460	< 29556	< 242	< 96	< 3177	< 348	< 6178	< 24	PGNoImp
0035	H002969	H002969.chn	09-Jul-12	2106	< 1196	< 167	< 8714	< 1319	< 2482	< 2405	< 28896	< 236	< 94	< 3106	< 340	< 6040	< 23	PGNoImp
0035	H002973	H002973.chn	10-Jul-12	2103	< 1197	< 167	< 8721	< 1320	< 2484	< 2407	< 28917	< 236	< 94	< 3108	< 340	< 6045	< 23	PGNoImp
0036	H003132	H003132.chn	11-Jul-12	2105	< 1196	< 167	< 8716	< 1319	< 2482	< 2406	< 28903	< 236	< 94	< 3106	< 340	< 6042	< 23	PGNoImp
0036	H003043	H003043.chn	12-Jul-12	2085	< 1202	< 168	< 8758	< 1326	< 2494	< 2417	< 29041	< 237	< 94	< 3121	< 342	< 6071	< 23	PGNoImp
0036	H003096	H003096.chn	10-Jul-12	1987	< 1231	< 172	< 8971	< 1358	< 2555	< 2476	< 29749	< 243	< 96	< 3197	< 350	< 6219	< 24	PGNoImp
0037	H003268	H003268.chn	28-Aug-12	2139	< 1187	< 166	< 8647	< 1309	< 2463	< 2387	< 28672	< 234	< 93	< 3082	< 337	< 5994	< 23	PGNoImp
0037	H003230	H003230.chn	27-Aug-12	2121	< 1192	< 167	< 8683	< 1314	< 2473	< 2397	< 28794	< 235	< 93	< 3095	< 339	< 6019	< 23	PGNoImp
0037	H003142	H003142.chn	29-Aug-12	2128	< 1190	< 166	< 8669	< 1312	< 2469	< 2393	< 28746	< 235	< 93	< 3090	< 338	< 6009	< 23	PGNoImp
0038	H002914	H002914.chn	23-Oct-12	1996	< 1228	< 172	< 8951	< 1355	< 2549	< 2471	< 29682	< 243	< 96	< 3190	< 349	< 6205	< 24	PGNoImp
0038	H002922	H002922.chn	17-Oct-12	1836	< 1281	< 179	< 9333	< 1413	< 2658	< 2576	< 30948	< 253	< 100	< 3326	< 364	< 6469	< 25	PGNoImp
0038	H002958	H002958.chn	23-Oct-12	1934	< 1248	< 174	< 9094	< 1376	< 2590	< 2510	< 30154	< 247	< 98	< 3241	< 355	< 6303	< 24	PGNoImp
0039	H002933	H002933.chn	11-Oct-12	1784	< 1299	< 182	< 9468	< 1433	< 2697	< 2613	< 31396	< 257	< 102	< 3374	< 369	< 6563	< 25	PGNoImp

BL No.	3013 ID	Spectrum File Name	Date Measured	Live Time	Al [ppm]	Be [ppm]	Cl [ppm]	F [ppm]	Mg [ppm]	P [ppm]	K [ppm]	Na [ppm]	F (HS) [ppm]	Mg (LS) [ppm]	Li (LLD) [ppm]	B (LLD) [ppm]	Be (HS) [ppm]	PG Category
0039	H002962	H002962.chn	16-Oct-12	1842	< 1279	< 179	< 9318	< 1410	< 2654	< 2572	< 30897	< 253	< 100	< 3321	< 363	< 6459	< 25	PGNoImp
0039	H002955	H002955.chn	11-Oct-12	1825	< 1285	< 180	< 9361	< 1417	< 2666	< 2584	< 31041	< 254	< 101	< 3336	< 365	< 6489	< 25	PGNoImp
0040	H002972	H002972.chn	06-Nov-12	2154	< 1182	< 165	< 8617	< 1304	< 2454	< 2378	< 28572	< 234	< 93	< 3071	< 336	< 5973	< 23	PGNoImp
0040	H002994	H002994.chn	07-Nov-12	2049	< 1212	< 170	< 8835	< 1337	< 2516	< 2438	< 29295	< 240	< 95	< 3149	< 345	< 6124	< 24	PGNoImp
0040	H002999	H002999.chn	06-Nov-12	2114	< 1194	< 167	< 8698	< 1316	< 2477	< 2401	< 28841	< 236	< 94	< 3100	< 339	< 6029	< 23	PGNoImp
0041	H002928	H002928.chn	07-Nov-12	2024	< 1220	< 171	< 8889	< 1345	< 2532	< 2453	< 29476	< 241	< 96	< 3168	< 347	< 6162	< 24	PGNoImp
0041	H002942	H002942.chn	07-Nov-12	2110	< 1195	< 167	< 8706	< 1318	< 2479	< 2403	< 28869	< 236	< 94	< 3103	< 340	< 6035	< 23	PGNoImp
0041	H002936	H002936.chn	08-Nov-12	2087	< 1201	< 168	< 8754	< 1325	< 2493	< 2416	< 29027	< 237	< 94	< 3120	< 341	< 6068	< 23	PGNoImp
0042	H002963	H002963.chn	08-Nov-12	2102	< 1197	< 167	< 8723	< 1320	< 2484	< 2408	< 28923	< 237	< 94	< 3109	< 340	< 6046	< 23	PGNoImp
0042	H002961	H002961.chn	19-Nov-12	1796	< 1295	< 181	< 9436	< 1428	< 2688	< 2605	< 31291	< 256	< 101	< 3363	< 368	< 6541	< 25	PGNoImp
0042	H002957	31-Jan-2013_H002957.Chn	31-Jan-13	7682	< 626	< 88	< 4563	< 691	< 1299	< 1259	< 15130	< 124	< 49	< 1626	< 178	< 3163	< 12	PGNoImp
0043	H002867	H002867.chn	18-Dec-12	2232	< 1162	< 162	< 8465	< 1281	< 2411	< 2336	< 28069	< 230	< 91	< 3017	< 330	< 5867	< 22	PGNoImp
0043	H003231	H003231.chn	18-Dec-12	2214	< 1166	< 163	< 8499	< 1286	< 2421	< 2346	< 28182	< 230	< 91	< 3029	< 332	< 5891	< 23	PGNoImp
0043	H003236	H003236.chn	12-Dec-12	2177	< 1176	< 164	< 8571	< 1297	< 2441	< 2366	< 28421	< 232	< 92	< 3055	< 334	< 5941	< 23	PGNoImp
0044	H002970	H002970.chn	13-Dec-12	2235	< 1161	< 162	< 8459	< 1280	< 2409	< 2335	< 28050	< 229	< 91	< 3015	< 330	< 5863	< 22	PGNoImp
0044	H002910	H002910.chn	18-Dec-12	2275	< 1151	< 161	< 8384	< 1269	< 2388	< 2314	< 27802	< 227	< 90	< 2988	< 327	< 5812	< 22	PGNoImp
0044	H003253	27-Feb-2013_H002970.Chn	27-Feb-13	7316	< 642	< 90	< 4675	< 708	< 1332	< 1290	< 15504	< 127	< 50	< 1666	< 182	< 3241	< 12	PGNoImp
0045	H003152	23-Jan-2013_H003152.Chn	23-Jan-13	6958	< 658	< 92	< 4794	< 726	< 1365	< 1323	< 15897	< 130	< 52	< 1709	< 187	< 3323	< 13	PGNoImp
0045	H003195	22-Jan-2013_H003195.Chn	22-Jan-13	7696	< 626	< 87	< 4559	< 690	< 1298	< 1258	< 15116	< 124	< 49	< 1625	< 178	< 3160	< 12	PGNoImp
0045	H003196	17-Jan-2013_H003196.Chn	17-Jan-13	6275	< 693	< 97	< 5048	< 764	< 1438	< 1393	< 16740	< 137	< 54	< 1799	< 197	< 3499	< 13	PGNoImp
0046	H003010	25-jan 2013 H003010.Chn	25-Jan-13	7547	< 632	< 88	< 4603	< 697	< 1311	< 1271	< 15264	< 125	< 49	< 1641	< 180	< 3191	< 12	PGNoImp
0046	H003002	24-Jan-2013_H003002.Chn	24-Jan-13	7454	< 636	< 89	< 4632	< 701	< 1319	< 1278	< 15359	< 126	< 50	< 1651	< 181	< 3211	< 12	PGNoImp

Appendix B: ARIES Prompt Gamma Results BL 1 through 89

BL No.	3013 ID	Spectrum File Name	Date Measured	Live Time	Al [ppm]	Be [ppm]	Cl [ppm]	F [ppm]	Mg [ppm]	P [ppm]	K [ppm]	Na [ppm]	F (HS) [ppm]	Mg (LS) [ppm]	Li (LLD) [ppm]	B (LLD) [ppm]	Be (HS) [ppm]	PG Category
0046	H003003	24-Jan-2013_H003003.Chn	24-Jan-13	7726	< 624	< 87	< 4550	< 689	< 1296	< 1256	< 15087	< 123	< 49	< 1621	< 177	< 3154	< 12	PGNoImp
0047	H002832	29-Jan-2013_H002832.Chn	29-Jan-13	7422	< 637	< 89	< 4642	< 703	< 1322	< 1281	< 15392	< 126	< 50	< 1654	< 181	< 3218	< 12	PGNoImp
0047	H002885	H002885.chn	07-Feb-13	2136	< 1187	< 166	< 8653	< 1310	< 2464	< 2388	< 28692	< 235	< 93	< 3084	< 338	< 5998	< 23	PGNoImp
0047	H002900	H002900.chn	05-Feb-13	2229	< 1162	< 163	< 8470	< 1282	< 2412	< 2338	< 28087	< 230	< 91	< 3019	< 330	< 5871	< 23	PGNoImp
0048	H003270	13-MAR-2013_H003270.Chn	13-Mar-13	6840	< 664	< 93	< 4835	< 732	< 1377	< 1335	< 16034	< 131	< 52	< 1723	< 189	< 3352	< 13	PGNoImp
0048	H002980	20-Feb-2013_H002980.Chn	20-Feb-13	7277	< 643	< 90	< 4688	< 710	< 1335	< 1294	< 15545	< 127	< 50	< 1671	< 183	< 3250	< 12	PGNoImp
0048	H003227	11-Mar-2013_H003227_2.Chn	11-Mar-13	7670	< 627	< 88	< 4566	< 691	< 1300	< 1260	< 15142	< 124	< 49	< 1627	< 178	< 3165	< 12	PGNoImp
0049	H002814	25-Mar-2013_H002814.Chn	25-Mar-13	7425	< 637	< 89	< 4641	< 702	< 1322	< 1281	< 15389	< 126	< 50	< 1654	< 181	< 3217	< 12	PGNoImp
0049	H002828	26-Mar-2013_H002828.Chn	26-Mar-13	7517	< 633	< 88	< 4613	< 698	< 1314	< 1273	< 15295	< 125	< 50	< 1644	< 180	< 3197	< 12	PGNoImp
0049	H002877	27-Mar-2013_H002877.Chn	27-Mar-13	7735	< 624	< 87	< 4547	< 688	< 1295	< 1255	< 15078	< 123	< 49	< 1621	< 177	< 3152	< 12	PGNoImp
0050	H002878	H002878.chn	25-Mar-13	2313	< 1141	185	< 8315	< 1259	< 2368	< 2295	< 27573	< 225	< 89	< 2964	< 324	< 5764	30	PGMisc
0050	H002892	H002892.chn	25-Mar-13	2316	< 1140	98	< 8310	< 1258	< 2367	< 2294	< 27555	< 225	< 89	< 2962	< 324	< 5760	16	PGMisc
0050	H002897	H002897.chn	25-Mar-13	2339	< 1135	267	< 8269	< 1252	< 2355	< 2282	< 27419	< 224	< 89	< 2947	< 323	< 5732	44	PGMisc
0051	H002943	21-Mar-2013_H002943.Chn	21-Mar-13	7052	< 654	< 91	< 4762	< 721	< 1356	< 1314	< 15791	< 129	< 51	< 1697	< 186	< 3301	< 13	PGNoImp
0051	H002977	H002977.chn	27-Mar-13	2372	< 1127	< 158	< 8211	< 1243	< 2339	< 2266	< 27228	< 223	< 88	< 2926	< 320	< 5692	< 22	PGNoImp
0051	H003257	H003257.chn	26-Mar-13	2308	< 1142	< 160	< 8324	< 1260	< 2371	< 2298	< 27603	< 226	< 89	< 2967	< 325	< 5770	< 22	PGNoImp
0052	H002868	H002868.chn	10-Apr-13	2364	< 1129	< 158	< 8225	< 1245	< 2343	< 2270	< 27274	< 223	< 88	< 2931	< 321	< 5701	< 22	PGNoImp
0052	H002893	H002893.chn	11-Apr-13	2272	< 1151	< 161	< 8390	< 1270	< 2389	< 2316	< 27820	< 228	< 90	< 2990	< 327	< 5816	< 22	PGNoImp
0052	H002915	H002915.chn	11-Apr-13	2361	< 1129	< 158	< 8230	< 1246	< 2344	< 2272	< 27291	< 223	< 88	< 2933	< 321	< 5705	< 22	PGNoImp

BL No.	3013 ID	Spectrum File Name	Date Measured	Live Time	Al [ppm]	Be [ppm]	Cl [ppm]	F [ppm]	Mg [ppm]	P [ppm]	K [ppm]	Na [ppm]	F (HS) [ppm]	Mg (LS) [ppm]	Li (LLD) [ppm]	B (LLD) [ppm]	Be (HS) [ppm]	PG Category
0053	H002926	17-Apr-2013_H002926.Chn	17-Apr-13	6690	< 671	< 94	< 4889	< 740	< 1392	< 1350	< 16213	< 133	< 53	< 1743	< 191	< 3389	< 13	PGNoImp
0053	H002821	18-Apr-2013_H002821.Chn	18-Apr-13	7166	< 648	< 91	< 4724	< 715	< 1345	< 1304	< 15665	< 128	< 51	< 1684	< 184	< 3275	< 13	PGNoImp
0053	H002949	15-Apr-2013_H002949.Chn	16-Apr-13	6988	< 657	< 92	< 4784	< 724	< 1362	< 1320	< 15863	< 130	< 51	< 1705	< 187	< 3316	< 13	PGNoImp
0054	H002987	H002987.Chn	26-Aug-14	1398	< 1468	< 205	< 10696	< 1619	< 3046	< 2952	< 35466	< 290	< 115	< 3812	< 417	< 7414	< 28	PGNoImp
0054	H003034	H003034.Chn	26-Aug-14	1281	< 1533	< 214	< 11173	< 1691	< 3182	< 3084	< 37050	< 303	< 120	< 3982	< 436	< 7745	< 30	PGNoImp
0054	H002995	H002995.Chn	26-Aug-14	1335	< 1502	< 210	< 10945	< 1657	< 3117	< 3021	< 36293	< 297	< 118	< 3901	< 427	< 7587	< 29	PGNoImp
0055	A002040	A002040.Chn	02-Aug-17	1242	< 1557	< 218	< 11348	< 1718	< 3232	< 3132	< 37628	< 308	< 122	< 4044	< 443	< 7866	< 30	PGNoImp
0055	A002046	A002046.Chn	02-Aug-17	1096	< 1658	< 232	< 12080	< 1828	< 3440	< 3334	< 40055	< 328	< 130	< 4305	< 471	< 8373	< 32	PGNoImp
0055	A002037	A002037.Chn	16-Aug-17	1032	< 1708	< 239	< 12449	< 1884	< 3545	< 3436	< 41279	< 338	< 134	< 4437	< 486	< 8629	< 33	PGNoImp
0056	A002035	A002035.Chn	08-Jun-17	1233	< 1563	< 219	< 11389	< 1724	< 3244	< 3143	< 37765	< 309	< 122	< 4059	< 444	< 7894	< 30	PGNoImp
0056	A002004	A002004.Chn	08-Jun-17	1414	< 1459	< 204	< 10635	< 1610	< 3029	< 2935	< 35265	< 288	< 114	< 3790	< 415	< 7372	< 28	PGNoImp
0056	A002032	A002032.Chn	15-Jun-17	1253	< 1550	< 217	< 11298	< 1710	< 3218	< 3118	< 37462	< 306	< 121	< 4026	< 441	< 7831	< 30	PGNoImp
0057	A002014	A002014.Chn	13-Sep-17	752	< 2001	< 280	< 14583	< 2207	< 4153	< 4025	< 48357	< 395	< 157	< 5197	< 569	< 10108	< 39	PGNoImp
0057	A002007	A002007.Chn	13-Sep-17	787	< 1956	< 274	< 14255	< 2158	< 4060	< 3935	< 47269	< 387	< 153	< 5081	< 556	< 9881	< 38	PGNoImp
0057	A002049	A002049.Chn	12-Sep-17	1434	< 1449	< 203	< 10561	< 1598	< 3008	< 2915	< 35018	< 286	< 114	< 3764	< 412	< 7320	< 28	PGNoImp
0058	A002024	A002024.Chn	13-Jul-17	914	< 1815	< 254	< 13228	< 2002	< 3767	< 3651	< 43863	< 359	< 142	< 4714	< 516	< 9169	< 35	PGNoImp
0058	A002045	A002045.Chn	15-Jun-17	1258	< 1547	< 216	< 11275	< 1707	< 3211	< 3112	< 37388	< 306	< 121	< 4018	< 440	< 7815	< 30	PGNoImp
0058	A002006	A002006.Chn	15-Jun-17	939	< 1791	< 250	< 13051	< 1975	< 3717	< 3602	< 43275	< 354	< 140	< 4651	< 509	< 9046	< 35	PGNoImp
0059	A002031	A002031.Chn	13-Jul-17	1086	< 1665	< 233	< 12135	< 1837	< 3456	< 3349	< 40239	< 329	< 130	< 4325	< 473	< 8412	< 32	PGNoImp
0059	A002016	A002016.Chn	02-Aug-17	1110	< 1647	< 230	< 12003	< 1817	< 3419	< 3313	< 39802	< 325	< 129	< 4278	< 468	< 8320	< 32	PGNoImp
0059	A002005	A002005.Chn	02-Aug-17	1074	< 1675	< 234	< 12203	< 1847	< 3475	< 3368	< 40464	< 331	< 131	< 4349	< 476	< 8458	< 32	PGNoImp
0060	A002039	A002039.Chn	16-Aug-17	839	< 1895	< 265	< 13806	< 2090	< 3932	< 3811	< 45781	< 374	< 148	< 4921	< 539	< 9570	< 37	PGNoImp
0060	A002012	A002012.Chn	26-Sep-17	827	< 1908	< 267	< 13906	< 2105	< 3961	< 3838	< 46112	< 377	< 149	< 4956	< 542	< 9639	< 37	PGNoImp
0060	A002041	A002041.Chn	26-Sep-17	1373	< 1481	< 207	< 10793	< 1634	< 3074	< 2979	< 35788	< 293	< 116	< 3846	< 421	< 7481	< 29	PGNoImp
0061	A002054	A002054.Chn	22-Jan-18	1104	< 1652	< 231	< 12036	< 1822	< 3428	< 3322	< 39910	< 326	81	< 4290	< 470	< 8343	< 32	PGFLo
0061	A002015	A002015.Chn	15-Feb-18	990	< 1744	< 244	< 12710	< 1924	< 3620	< 3508	< 42145	< 345	161	< 4530	< 496	< 8810	< 34	PGFLo

Appendix B: ARIES Prompt Gamma Results BL 1 through 89

BL No.	3013 ID	Spectrum File Name	Date Measured	Live Time	Al [ppm]	Be [ppm]	Cl [ppm]	F [ppm]	Mg [ppm]	P [ppm]	K [ppm]	Na [ppm]	F (HS) [ppm]	Mg (LS) [ppm]	Li (LLD) [ppm]	B (LLD) [ppm]	Be (HS) [ppm]	PG Category
0061	A002082	A002082.Chn	22-Jan-18	1245	< 1555	< 217	< 11334	< 1715	< 3228	< 3128	< 37582	611	123	< 4039	< 442	< 7856	< 30	PGFLo
0062	A002060	A002060.Chn	12-Sep-17	1115	< 1644	< 230	< 11976	< 1813	< 3411	< 3306	< 39713	< 325	< 129	< 4268	< 467	< 8301	< 32	PGNoImp
0062	A002048	A002048.Chn	20-Sep-17	1084	< 1667	< 233	< 12146	< 1838	< 3459	< 3353	< 40277	< 329	< 131	< 4329	< 474	< 8419	< 32	PGNoImp
0062	A002026	A002026.Chn	20-Sep-17	1139	< 1626	< 227	< 11849	< 1794	< 3375	< 3271	< 39292	< 321	< 127	< 4223	< 462	< 8214	< 31	PGNoImp
0063	A002028	A002028.Chn	15-Feb-18	1229	< 1565	< 219	< 11407	< 1727	< 3249	< 3149	< 37826	< 309	< 123	< 4066	< 445	< 7907	< 30	PGNoImp
0063	A002003	A002003.Chn	22-Feb-18	924	< 1805	< 252	< 13156	< 1991	< 3747	< 3631	< 43625	< 357	< 141	< 4689	< 513	< 9119	< 35	PGNoImp
0063	A002025	A002025.Chn	08-Mar-18	692	< 2086	< 292	< 15202	< 2301	< 4330	< 4196	< 50410	< 412	< 163	< 5418	< 593	< 10538	< 40	PGNoImp
0064	A002117	A002117.Chn	21-Mar-18	1092	< 1661	< 232	< 12102	< 1832	< 3447	< 3340	< 40129	< 328	< 130	< 4313	< 472	< 8388	< 32	PGNoImp
0064	A002119	A002119.Chn	21-Mar-18	1085	< 1666	< 233	< 12141	< 1838	< 3458	< 3351	< 40258	< 329	< 131	< 4327	< 474	< 8415	< 32	PGNoImp
0064	A002027	A002027.Chn	08-Mar-18	698	< 2077	< 290	< 15137	< 2291	< 4311	< 4178	< 50193	< 410	< 163	< 5395	< 590	< 10492	< 40	PGNoImp
0065	A002092	A002092.Chn	28-Mar-18	1085	< 1666	< 233	< 12141	< 1838	< 3458	< 3351	< 40258	< 329	< 131	< 4327	< 474	< 8415	< 32	PGNoImp
0065	A002013	A002013.Chn	22-Mar-18	1553	< 1393	< 195	< 10148	< 1536	< 2890	< 2801	< 33650	< 275	< 109	< 3617	< 396	< 7034	< 27	PGNoImp
0065	A002050	A002050.Chn	22-Mar-18	1542	< 1398	< 195	< 10184	< 1541	< 2900	< 2811	< 33770	< 276	< 109	< 3630	< 397	< 7059	< 27	PGNoImp
0066	A002020	A002020.Chn	30-Apr-18	1238	< 1560	< 218	< 11366	< 1720	< 3237	< 3137	< 37688	< 308	< 122	< 4051	< 443	< 7878	< 30	PGNoImp
0066	A002044	A002044.Chn	30-Apr-18	1229	< 1565	< 219	< 11407	< 1727	< 3249	< 3149	< 37826	< 309	< 123	< 4066	< 445	< 7907	< 30	PGNoImp
0066	A002002	A002002.Chn	01-May-18	1351	< 1493	< 209	< 10880	< 1647	< 3099	< 3003	< 36078	< 295	< 117	< 3878	< 424	< 7542	< 29	PGNoImp
0067	A002122	A002122.Chn	14-Jun-18	1205	< 1581	883	< 11520	< 1744	< 3281	< 3180	< 38201	< 312	< 124	< 4106	< 449	< 7985	145	PGMisc
0067	A002123	A002123.Chn	14-Jun-18	1274	< 1538	870	< 11204	< 1696	< 3191	< 3092	< 37152	< 304	< 120	< 3993	< 437	< 7766	143	PGMisc
0067	A002124	A002124.Chn	14-Jun-18	1349	< 1494	939	< 10888	< 1648	< 3101	< 3005	< 36104	< 295	< 117	< 3881	< 425	< 7547	155	PGMisc
0067	A002122	20200825_161116_a002122_pg12hr.chn	25-Aug-20	29050	< 322	611	< 2346	< 355	< 668	< 648	< 7780	319	< 25	< 836	< 92	< 1626	101	PGMisc
0068	A002084	A002084.Chn	11-Sep-18	660	< 2136	< 299	< 15566	< 2356	< 4433	< 4296	< 51617	< 422	< 167	< 5548	< 607	< 10790	< 41	PGNoImp
0068	A002114	A002114.Chn	11-Sep-18	949	< 1781	< 249	< 12982	< 1965	< 3697	< 3583	< 43046	< 352	< 140	< 4627	< 506	< 8998	< 34	PGNoImp
0068	A002113	A002113.Chn	11-Sep-18	764	< 1985	< 278	< 14468	< 2190	< 4121	< 3993	< 47976	< 392	< 156	< 5156	< 564	< 10029	< 38	PGNoImp
0069	A002023	A002023.Chn	19-Sep-18	1408	< 1463	< 204	< 10658	< 1613	< 3035	< 2942	< 35340	< 289	< 115	< 3798	< 416	< 7387	< 28	PGNoImp
0069	A002126	A002126.Chn	19-Sep-18	1323	< 1509	< 211	< 10995	< 1664	< 3131	< 3035	< 36458	< 298	< 118	< 3918	< 429	< 7621	< 29	PGNoImp
0069	A002127	A002127.Chn	20-Sep-18	1276	< 1536	< 215	< 11195	< 1694	< 3188	< 3090	< 37123	< 304	< 120	< 3990	< 437	< 7760	< 30	PGNoImp
0070	A002106	A002106.Chn	03-Oct-18	1242	< 1557	< 218	< 11348	< 1718	< 3232	< 3132	< 37628	< 308	< 122	< 4044	< 443	< 7866	< 30	PGNoImp
0070	A002118	A002118.Chn	03-Oct-18	1334	< 1503	< 210	< 10949	< 1657	< 3118	< 3022	< 36307	< 297	< 118	< 3902	< 427	< 7590	< 29	PGNoImp
0070	A002128	A002128.Chn	03-Oct-18	1152	< 1617	< 226	< 11782	< 1783	< 3356	< 3252	< 39070	< 319	< 127	< 4199	< 460	< 8167	< 31	PGNoImp

BL No.	3013 ID	Spectrum File Name	Date Measured	Live Time	Al [ppm]	Be [ppm]	Cl [ppm]	F [ppm]	Mg [ppm]	P [ppm]	K [ppm]	Na [ppm]	F (HS) [ppm]	Mg (LS) [ppm]	Li (LLD) [ppm]	B (LLD) [ppm]	Be (HS) [ppm]	PG Category
0071	A002105	A002105.Chn	05-Dec-18	857	< 1875	< 262	< 13661	< 2068	< 3891	< 3770	< 45298	< 370	< 147	< 4869	< 533	< 9469	< 36	PGNoImp
0071	A002110	A002110.Chn	05-Dec-18	852	< 1880	< 263	< 13701	< 2074	< 3902	< 3782	< 45430	< 372	< 147	< 4883	< 534	< 9497	< 36	PGNoImp
0071	A002137	A002137.Chn	05-Dec-18	846	< 1887	< 264	< 13749	< 2081	< 3916	< 3795	< 45591	< 373	< 148	< 4900	< 536	< 9530	< 37	PGNoImp
0072	A002093	A002093.Chn	17-Apr-19	1212	< 1576	< 220	< 11487	< 1739	< 3272	< 3171	< 38090	< 311	< 123	< 4094	< 448	< 7962	< 30	PGNoImp
0072	A002097	A002097.Chn	17-Apr-19	1132	< 1631	< 228	< 11886	< 1799	< 3385	< 3281	< 39413	< 322	< 128	< 4236	< 464	< 8239	< 32	PGNoImp
0072	A002101	A002101.Chn	17-Apr-19	1168	< 1606	< 225	< 11701	< 1771	< 3333	< 3230	< 38801	< 317	< 126	< 4170	< 456	< 8111	< 31	PGNoImp
0073	A002139	A002139.Chn	13-Jun-19	1155	< 1615	< 226	< 11767	< 1781	< 3351	< 3248	< 39019	< 319	< 126	< 4194	< 459	< 8156	< 31	PGNoImp
0073	A002141	A002141.Chn	13-Jun-19	1251	< 1552	< 217	< 11307	< 1711	< 3220	< 3121	< 37492	< 307	< 122	< 4030	< 441	< 7837	< 30	PGNoImp
0073	A002103	A002103.Chn	18-Apr-19	1269	< 1541	< 215	< 11226	< 1699	< 3197	< 3099	< 37225	< 304	< 121	< 4001	< 438	< 7781	< 30	PGNoImp
0074	A002098	A002098.Chn	18-Apr-19	1015	< 1723	< 241	< 12552	< 1900	< 3575	< 3465	< 41623	< 340	< 135	< 4474	< 490	< 8701	< 33	PGNoImp
0074	A002109	A002109.Chn	16-Apr-19	1123	< 1638	< 229	< 11934	< 1806	< 3399	< 3294	< 39571	< 324	< 128	< 4253	< 466	< 8272	< 32	PGNoImp
0074	A002111	A002111.Chn	16-Apr-19	1214	< 1575	< 220	< 11478	< 1737	< 3269	< 3168	< 38059	< 311	< 123	< 4091	< 448	< 7956	< 30	PGNoImp
0075	A002548	A002548.Chn	15-Apr-19	1042	< 1700	692	< 12389	< 1875	< 3528	1728	< 41080	< 336	98	< 4415	< 483	< 8587	114	PGFLo
0075	A002549	A002549.Chn	15-Apr-19	749	< 2005	673	< 14612	< 2212	< 4162	2022	< 48454	< 396	74	< 5208	< 570	< 10129	111	PGFLo
0075	A002547	A002547.Chn	15-Apr-19	904	< 1825	727	< 13301	< 2013	< 3788	1361	< 44104	< 361	63	< 4740	< 519	< 9220	120	PGFLo
0076	A002102	A002102.Chn	17-Apr-19	1262	< 1545	867	< 11257	< 1704	< 3206	< 3107	< 37328	< 305	< 121	< 4012	< 439	< 7803	143	PGMisc
0076	A002108	A002108.Chn	17-Apr-19	1083	< 1668	787	< 12152	< 1839	< 3461	< 3354	< 40295	< 330	< 131	< 4331	< 474	< 8423	130	PGMisc
0076	A002083	A002083.Chn	16-Apr-19	1260	< 1546	805	< 11266	< 1705	< 3209	< 3110	< 37358	< 305	< 121	< 4015	< 439	< 7809	133	PGMisc
0077	A002339	A002339.Chn	08-Jul-19	1064	< 1682	< 235	< 12260	< 1856	< 3492	< 3384	< 40653	< 332	< 132	< 4369	< 478	< 8498	< 32	PGNoImp
0077	A002138	20210405_153244_a002138_10hr_pg.chn	05-Apr-21	24390	< 351	41	< 2561	< 388	< 729	< 707	< 8491	< 69	< 28	< 913	< 100	< 1775	7	PGMisc
0077	A002142	A002142.Chn	08-Jul-19	1259	< 1547	< 216	< 11271	< 1706	< 3210	< 3111	< 37373	< 306	< 121	< 4017	< 440	< 7812	< 30	PGNoImp
0078	A002149	A002149.Chn	18-Jul-19	993	< 1742	< 243	< 12691	< 1921	< 3614	< 3503	< 42082	< 344	< 136	< 4523	< 495	< 8797	< 34	PGNoImp
0078	A002164	A002164.Chn	18-Jul-19	1022	< 1717	< 240	< 12509	< 1893	< 3563	< 3453	< 41480	< 339	< 134	< 4458	< 488	< 8671	< 33	PGNoImp
0078	A002175	A002175.Chn	18-Jul-19	957	< 1774	< 248	< 12927	< 1957	< 3682	< 3568	< 42866	< 351	< 139	< 4607	< 504	< 8961	< 34	PGNoImp
0079	A002187	A002187.Chn	14-Aug-19	1378	< 1478	< 207	< 10773	< 1631	< 3068	< 2973	< 35723	< 292	< 116	< 3839	< 420	< 7467	< 29	PGNoImp
0079	A002180	A002180.Chn	12-Aug-19	981	< 1752	< 245	< 12768	< 1933	< 3636	< 3524	< 42338	< 346	< 137	< 4551	< 498	< 8850	< 34	PGNoImp

Appendix B: ARIES Prompt Gamma Results BL 1 through 89

BL No.	3013 ID	Spectrum File Name	Date Measured	Live Time	Al [ppm]	Be [ppm]	Cl [ppm]	F [ppm]	Mg [ppm]	P [ppm]	K [ppm]	Na [ppm]	F (HS) [ppm]	Mg (LS) [ppm]	Li (LLD) [ppm]	B (LLD) [ppm]	Be (HS) [ppm]	PG Category
0079	A002166	20210126_165149_a002166-pg-10hr.chn	26-Jan-21	24470	< 351	42	< 2556	< 387	< 728	< 706	< 8477	< 69	13	< 911	< 100	< 1772	7	PGFLo
0080	A002179	A002181.Chn	04-Sep-19	924	< 1805	< 252	< 13156	< 1991	< 3747	< 3631	< 43625	< 357	< 141	< 4689	< 513	< 9119	< 35	PGNoImp
0080	A002182	A002182.Chn	05-Sep-19	1694	< 1333	< 186	< 9716	< 1471	< 2767	< 2682	< 32219	< 263	< 104	< 3463	< 379	< 6735	< 26	PGNoImp
0080	A002173	A002173.Chn	04-Sep-19	913	< 1816	< 254	< 13235	< 2003	< 3769	< 3653	< 43887	< 359	< 142	< 4717	< 516	< 9174	< 35	PGNoImp
0081	A002172	A002172.Chn	13-Nov-19	2682	< 1060	< 148	< 7722	< 1169	< 2199	< 2131	< 25606	< 209	< 83	< 2752	< 301	< 5353	< 20	PGNoImp
0081	A002177	A002177.Chn	13-Nov-19	2508	< 1096	< 153	< 7985	< 1209	< 2274	< 2204	< 26479	< 217	< 86	< 2846	< 312	< 5535	< 21	PGNoImp
0081	A002159	A002159.Chn	13-Nov-19	2423	< 1115	< 156	< 8124	< 1230	< 2314	< 2242	< 26940	< 220	< 87	< 2895	< 317	< 5631	< 22	PGNoImp
0082	A002171	A002171.Chn	18-Feb-20	2268	< 1152	< 161	< 8397	< 1271	< 2392	< 2318	< 27845	< 228	< 90	< 2993	< 328	< 5821	< 22	PGNoImp
0082	A002183	A002183.Chn	18-Feb-20	2285	< 1148	< 161	< 8366	< 1266	< 2383	< 2309	< 27741	< 227	< 90	< 2982	< 326	< 5799	< 22	PGNoImp
0082	A002160	A002160.Chn	18-Feb-20	2187	< 1174	< 164	< 8551	< 1294	< 2435	< 2360	< 28356	< 232	< 92	< 3048	< 334	< 5927	< 23	PGNoImp
0083	A002186	A002186.Chn	01-Jun-20	1509	< 1413	684	< 10295	< 1558	< 2932	< 2841	< 34137	< 279	< 111	< 3669	< 402	< 7136	113	PGMisc
0083	A002125	A002125.Chn	19-Feb-20	2211	< 1167	594	< 8505	< 1287	< 2422	< 2347	< 28202	< 231	< 91	< 3031	< 332	< 5895	98	PGMisc
0083	A002333	A002333.Chn	01-Jun-20	1489	< 1422	663	< 10364	< 1569	< 2952	< 2860	< 34365	< 281	< 111	< 3694	< 404	< 7184	109	PGMisc
0084	A002519	A002519.Chn	01-Jun-20	1546	< 1396	217	3571	< 1539	837	< 2807	< 33726	693	73	< 3625	< 397	< 7050	36	PGCl
0084	A002514	A002514.Chn	01-Jun-20	1493	< 1420	182	5977	< 1567	1715	< 2857	< 34319	696	29	< 3689	< 404	< 7174	30	PGCl
0084	A002515	A002515.Chn	01-Jun-20	844	< 1889	140	6254	< 2083	750	< 3799	< 45645	730	80	< 4906	< 537	< 9542	23	PGCl
0085	A002576	A002576.Chn	08-Feb-21	1910	< 1256	4261	6986	< 1385	6112	< 2526	< 30342	1952	205	< 3261	< 357	< 6343	702	PGCl
0085	A002562	A002562.Chn	04-Feb-21	1736	< 1317	4263	3135	< 1453	5565	< 2649	< 31827	1894	191	< 3421	< 374	< 6653	702	PGCl
0085	A002584	A002584.Chn	04-Feb-21	1715	< 1325	4298	10514	< 1462	5062	< 2665	< 32021	1739	326	< 3442	< 377	< 6694	708	PGCl
0086	A002586	A002586.Chn	04-Feb-21	1697	< 1332	< 186	< 9708	< 1469	2074	< 2679	< 32190	< 263	8	< 3460	< 379	< 6729	< 26	PGFLo
0086	A002583	A002583.Chn	04-Feb-21	1782	< 1300	< 182	< 9473	< 1434	< 2698	< 2615	< 31413	< 257	41	< 3376	< 370	< 6567	< 25	PGFLo
0086	A002582	A002582.Chn	08-Feb-21	1935	< 1248	< 174	< 9091	< 1376	2221	< 2509	< 30146	< 247	30	< 3240	< 355	< 6302	< 24	PGFLo
0087	A002585	A002585.Chn	08-Feb-21	1908	853	1852	4791	< 1386	2050	< 2527	< 30358	1862	500	< 3263	< 357	< 6346	305	PGCl
0087	A002575	A002575.Chn	09-Feb-21	2044	< 1214	1843	6415	< 1339	1956	< 2441	< 29331	1950	608	< 3152	< 345	< 6131	303	PGCl
0087	A002557	A002557.Chn	08-Feb-21	2034	< 1217	1938	3719	< 1342	3037	< 2447	< 29403	1812	542	< 3160	< 346	< 6146	319	PGCl
0088	A002573	A002573.Chn	02-Feb-21	1517	< 1409	< 197	< 10268	< 1554	2095	< 2834	< 34047	< 278	560	< 3659	< 401	< 7117	< 27	PGFLo
0088	A002589	A002589.Chn	03-Feb-21	1348	< 1495	< 209	< 10892	< 1649	951	< 3006	< 36118	< 295	454	< 3882	< 425	< 7550	< 29	PGFLo
0088	A002550	A002550.Chn	02-Feb-21	1480	< 1427	< 199	< 10395	390	1514	< 2869	< 34470	< 282	531	< 3705	< 406	< 7205	< 28	PGFLo

BL No.	3013 ID	Spectrum File Name	Date Measured	Live Time	Al [ppm]	Be [ppm]	Cl [ppm]	F [ppm]	Mg [ppm]	P [ppm]	K [ppm]	Na [ppm]	F (HS) [ppm]	Mg (LS) [ppm]	Li (LLD) [ppm]	B (LLD) [ppm]	Be (HS) [ppm]	PG Category
0089	A002570	A002570.Chn	03-Feb-21	1701	< 1331	< 186	< 9696	< 1468	1194	< 2676	< 32153	232	< 104	< 3456	< 378	< 6721	< 26	PGMisc
0089	A002565	A002565.Chn	03-Feb-21	1711	< 1327	< 185	< 9668	< 1463	1409	< 2668	< 32058	202	< 104	< 3446	< 377	< 6701	< 26	PGMisc
0089	A002559	A002559.Chn	02-Feb-21	1657	< 1348	< 188	< 9824	< 1487	1724	< 2712	< 32577	193	< 106	< 3501	< 383	< 6810	< 26	PGMisc